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ABSTRACT

This document contains an extensive review of the literature concerning control and display technology that is applicable to the Orbital Maneuvering Vehicle (OMV), a system being developed by NASA that will enable the user to remotely pilot it during a mission in space. In addition to the general review, special consideration is given to virtual image displays and their potential for use in the system, and a preliminary partial task analysis of the user's functions is also presented.

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DISPLAYS

The OMV display panel will serve as the operator's source of information as he performs the various piloting functions. Effectively monitoring and interpreting the OMV is a primary objective in the design of the display system. An effective display must consider information priority and event criticality. In the most critical situations there is a period of time or time envelope in which the operator must take appropriate action. If the operator acts outside of the time envelope his actions may occur too late to permit corrective responses. The time between operator detection of an input and the boundaries of the time envelope are generally used to develop a priority system dictating the general configuration of the display. Consideration is also given to the potential impact of system failure in developing a priority system. In this manner a hierarchical display concept evolves from the operator's functional analysis of the priorities of input an impact of input failures.

The major objective of this literature review is to develop guidelines for optimal signal effectiveness in the OMV. To accomplish this objective it is necessary to look at types of input signals that can be used, factors affecting detection and factors affecting time from detection to performance of the appropriate response. In this regard, it should be noted that most reaction time studies are measures of simple reaction time in which the subject's only task is detecting and responding to a signal. In the operational OMV environment the operator will have other tasks to perform. As a result, the reaction time literature must be viewed as performance under optimal conditions.

In the aerospace environment vision and audition have been the dominant display modalities. Several authors have indicated that touch can be successfully utilized. In terms of detection of visual, of auditory, or tactile inputs one must consider the physical characteristics of the input and the nature of the working environment in which inputs occur.

VISUAL DISPLAYS

Stimulus Factors Affecting Signal Detection

Location. Visual inputs are detected best if located in a normal line of sight and highest priority inputs are to be located no more than +/- 15 degrees from a normal line of sight. Standard references have established that primary inputs should be inside a circle with a radius of 15 degrees from a normal line of sight and secondary signals inside a 30 degree circle (McCormick, 1976).

Rich et al. (1971) using a Cessna cockpit flight simulator found subjects able to detect 85% of the input within the normal line of sight. Only 35% of the targets 30 degrees and 40 degrees from the line of sight were detected.

Sharp (1967) had subjects perform a tracking task. At different visual angles from 0 to 96.5 degrees either combined visual and auditory inputs or visual inputs alone were presented. Without a warning tone, response times doubled. At the outermost visual angle of 96.5 degrees, a quarter of the inputs were not responded to or missed.

Response time to various colors has been extensively studied by Haines (1975). Using a simple R.T. paradigm he mapped zones of equal reaction time (iso-RT zone) for red, green, yellow, blue and white, for monocular and binocular field of view. Missed inputs or no-response for all colors increased rapidly beyond 30 degrees reaching 100% at the periphery. These findings amplify the importance of a normal line of sight or where the operator will be looking. A thorough function/task analysis should be sensitive to exactly where the OMV operator will be looking during various stages of a mission. High priority inputs must be located where he or she is looking.

The OMV piloting task will require tracking and docking during proximity operations. As a result, caution and warning signals that may occur could be missed. A failure mode analysis would establish failures that could occur during proximity operations. These failures would need to be prioritized and an appropriate alerting system would need to be human engineered.

A three step priority system is primarily used in aerospace. The lowest priority step is a "caution" that does not require immediate attention, but informs the operator of an off nominal condition in which a relatively large time envelope exists for correction. The second priority is a "warning." A warning represents a more serious threat to the mission with a relatively shorter envelope to make corrections. The highest priority is an "emergency" indicating a severe alert potentially endangering the crew and/or mission and requiring immediate attention and response. When the time envelope for correction is short, operators frequently not only require an appropriately designed caution-warning system, but also require rather specific information relative to how to correct the problem.

As a result, appropriate human engineering caution-warning systems using today's display technology may utilize a blinking light for a "caution", a blinking light and tone for a "warning", and a blinking light, tone, and a voice display informing the operator of the problem and where to look for possible corrective actions. During proximity operations all caution and warning signals should be presented on the display monitor because visual displays on the display panel would in all likelihood be missed while the operator is performing a precision tracking task. Even a blinking red light will be no more attention provoking than any other color while the operator is tracking.

Size of visual inputs and detections. A thorough review of existing literature indicate that higher priority visual inputs should subtend at least a 1 degree visual angle, whereas lower priority signals should subtend at least a .5 degree visual angle.

Blackwell (1946), using different contrasts and background luminance, determined the smallest size signal that could be detected. Figure 1 presents his results in which the contrast was the absolute value of signal brightness minus the background.

Sheehan (1972) using an A-7E heads-up display simulator, evaluated response times to alphanumeric legends. Three different visual warnings were used to which subjects had to detect and respond. Figure 2 presents response time as a function of character height. As can be seen, response time was cut in half by increasing character heights from 0.5 to 1 degree.

As noted above for detecting high priority signals and alphanumeric legends should be no smaller than 1

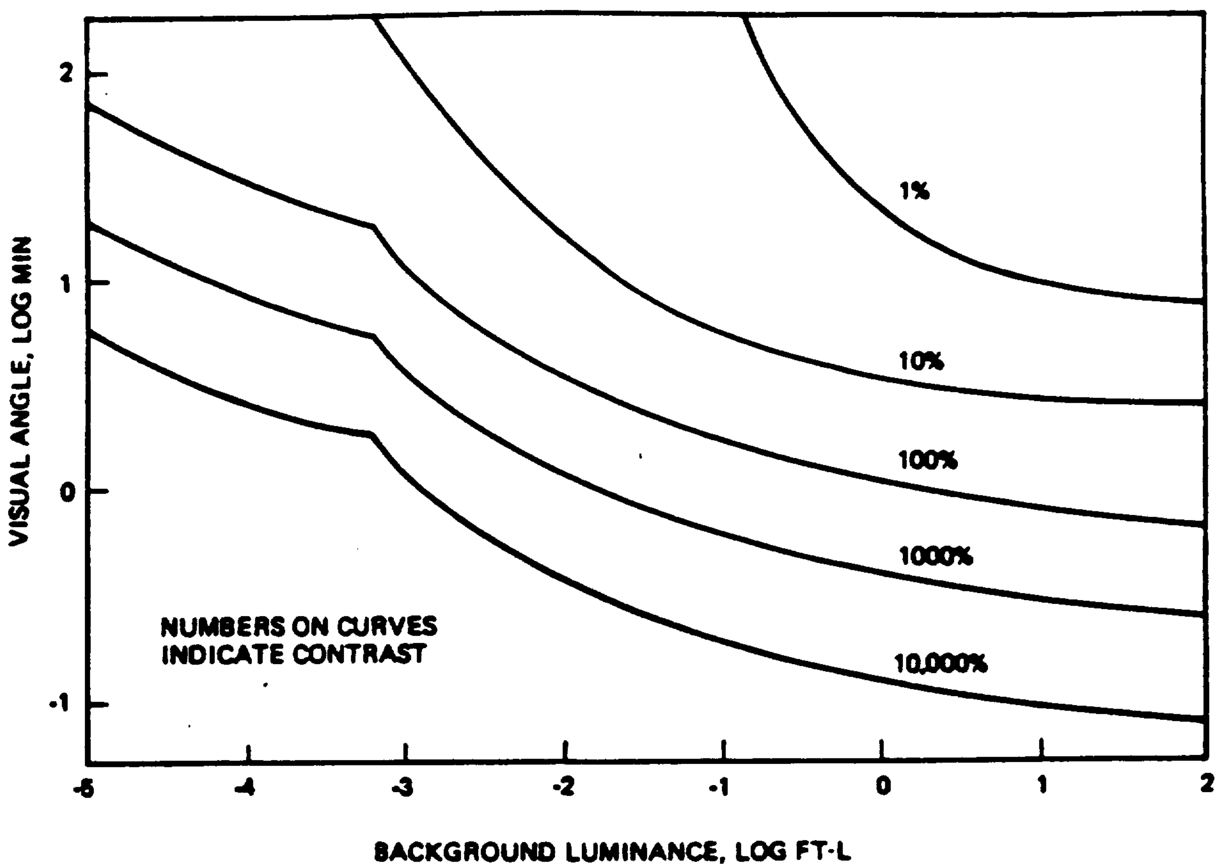


Figure 1 Minimum Perceptibility, or Spot Detection, for Circular Targets as a Function of Contrast and Background Luminance (Blackwell, 1946)

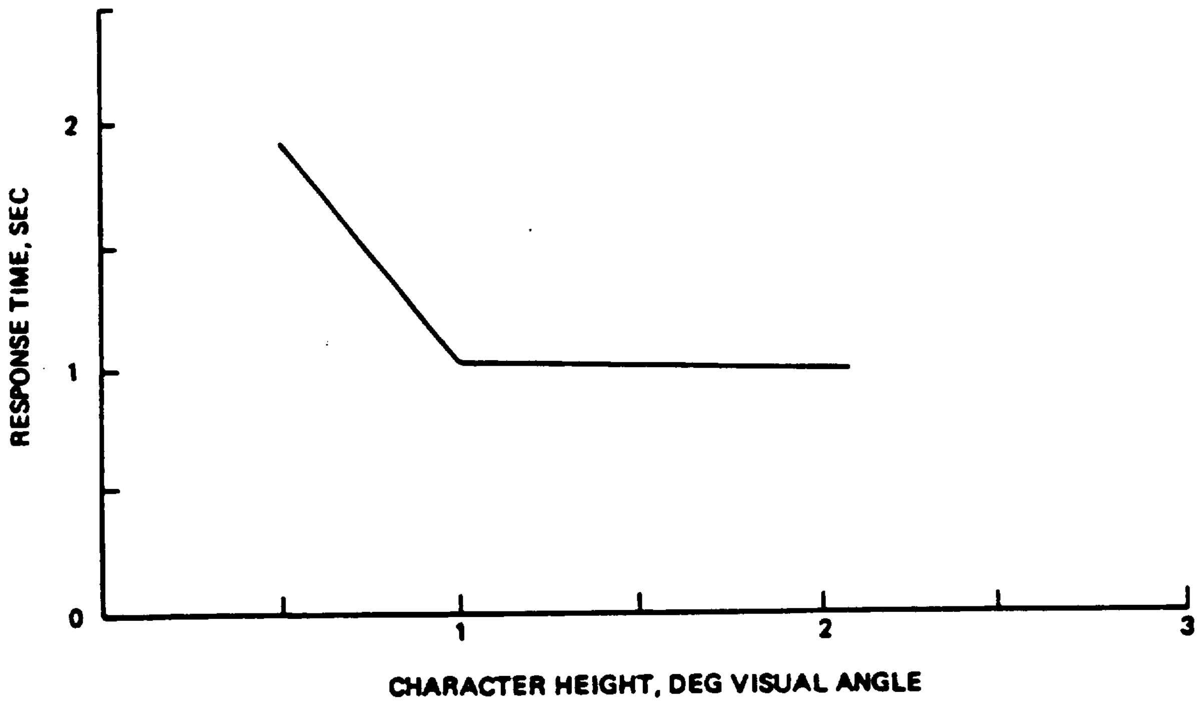


Figure 2 Effect of Character Height in Reaction Time

degree visual angle. Lesser signals should be no smaller than 0.5 degree whether displayed on the OMV panel or monitor.

Compliance with these research findings will enhance the operator's ability to detect a signal and discriminate it from the busy monitor.

Brightness of visual signals and detection. Highest priority signals should be at least twice as bright as other signals (Meister & Sullivan, 1969). Lower priority signals should be at least 10% brighter than other signals. Military standards require a minimum of 150 ft. L for high priority signals and 15 ft. L for low. White and Schneyder (1960) recommend a minimum of 100 ft. L for high priority signals and 5 to 10 ft. L for all other signals. As signal intensity increases, simple reaction time will decrease (Davis, 1947; Luckiesk, 1944; Steinman, 1944; and Steinman and Venias, 1944). Typical results are plotted in Figure 3 (Kohfeld, 1971).

Detection of steady state and flashing signals. If all other signals are steady state, flashing lights are easiest to detect. Ideally, all background lights should be steady state or go off when a flashing warning light occurs. Crawford (1962, 1963) found that if the background is all steady state lights, then flashing lights will be detected faster than steady state lights.

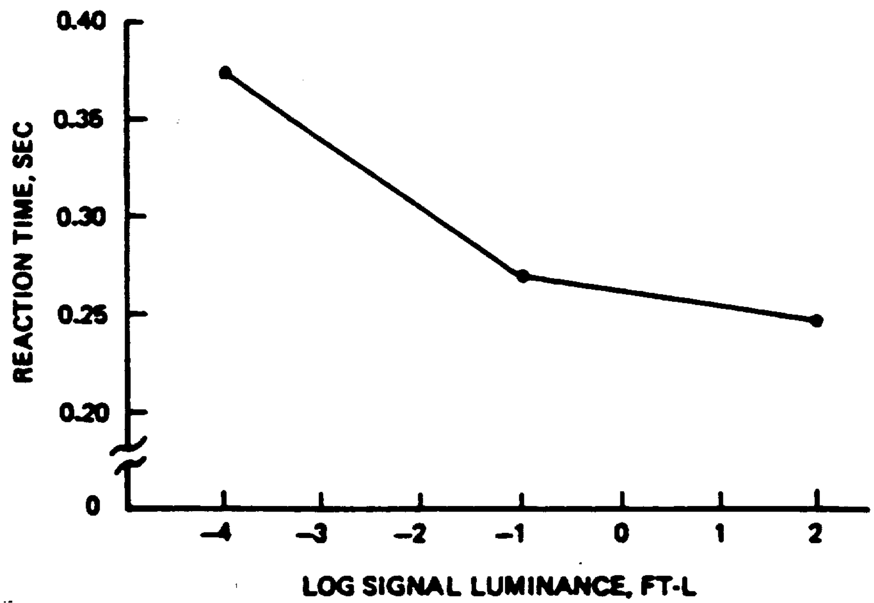


Figure 3 Simple Reaction Times as a Function of Signal Luminance (Kohfeld 1971)

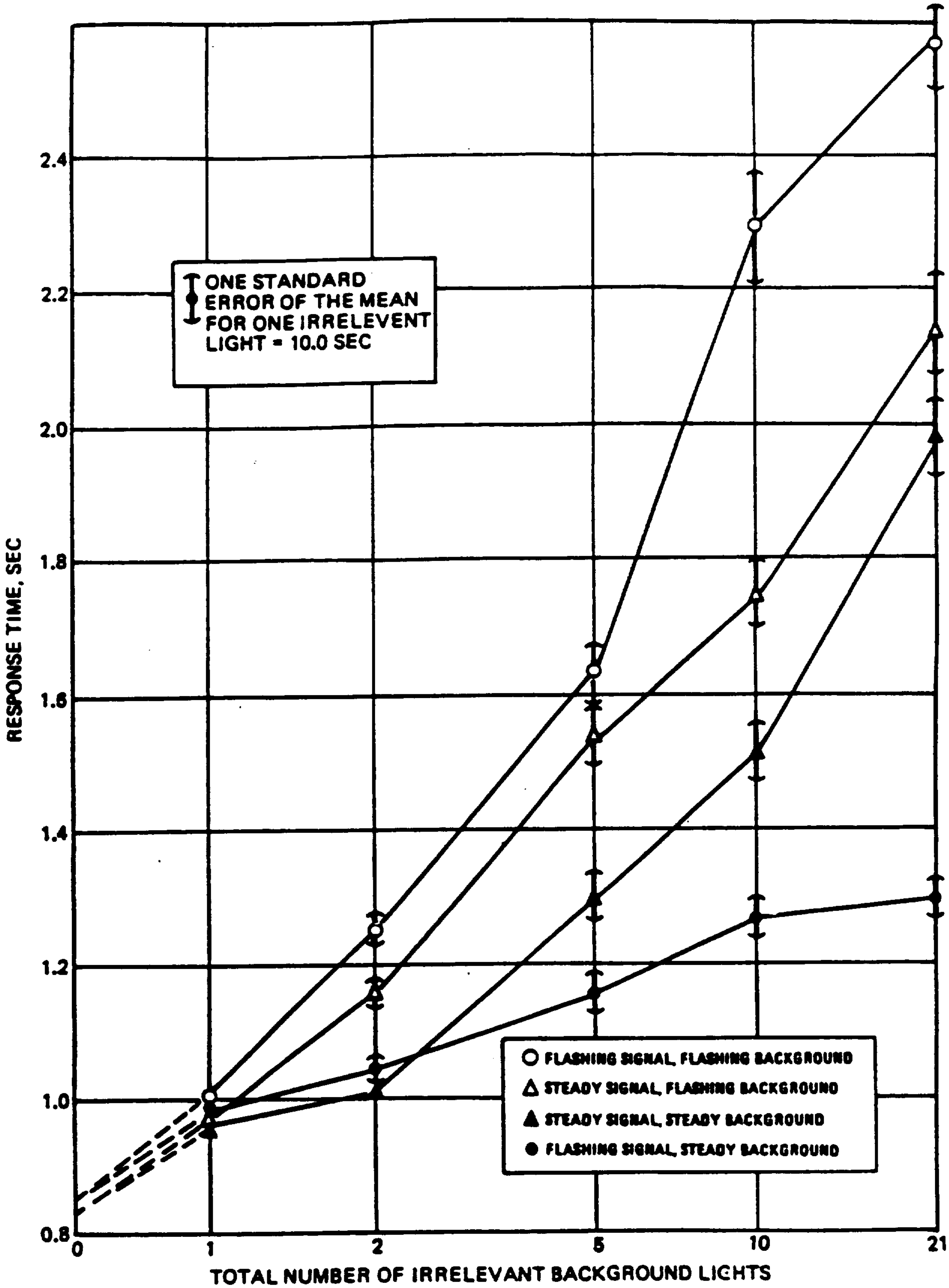


Figure 4 *Effects of Irrelevant Background Lights on Response Time* *(Crawford 1962)*

Detection times for flashing signals were proportional to the inverse of the log of the number of steady state lights. Figure 4 presents Crawford's findings that have generally held up in other research (e.g. Edwards, 1971).

Color and visual signal detection. Findings from studies of the effect of color on detection time have shown color to have little effect (Weingarten, 1972). In general, color does not decrease response time for signals of moderate to high intensity when presented on a dark background. When colors are used the conventional population stereotypes should be used, i.e. red - highest priority; amber - caution'; green or blue - normal or safe (Boucek et al., 1977). Some research has found response time to red to be shorter than to other colors (Reynolds et al., 1972; Hill, 1947). Haines (1975) essentially found no differences among colors in regard to reaction time. Assignment of color, then, to visual signals is largely a matter of consistency with established population stereotypes and concurrence with Federal airworthinesss regulations.

It is recommended that in the OMV visual display environment that all visual signals subtend a visual angle of 1 degree if it is to be used in the caution-warning system, and that "cautions" be displayed on the monitor at least 10% brighter than other information displayed on the monitor. It is recommended that "warning" and "emergency" information be presented at a brightness of 150 ft L. in a steady state for caution and flashing in an emergency. Steady state amber should be used for "caution" signals and flashing amber for "warnings". Flashing red should be used exclusively for "emergencies".

Alphanumeric Displays. Tullis (1983) analyzed the literature dealing with the formatting of alphanumeric displays. Due to the broadness of this topic, he focused on computer-generated, monochromatic, alphanumeric, formatted displays. He reviewed guidelines, that may be either highly general of very specific, and empirical studies concerning display design. The empirical studies generally used either simple, artificial displays or complex, realistic ones, with both types involving tasks of either question answering, problem solving, reading, or subjective ratings. He selected characteristics that were related to spatial design, that could be objectively defined, and that were applicable to any alphanumeric display. Using these criteria, the following characteristics were selected: overall density, the number of filled character spaces near each character, grouping, the extent to which items form well-defined groups, and layout complexity. Layout complexity refers to the extent to which the arrangement of items on the frame follows a predictable visual scheme.

The guidelines concerning overall density commonly state that only "relevant" information should be displayed (Cakir, Hart, and Stewart, 1980; Galitz, 1980), or that the display should not be "cluttered" (Green, 1976; Peterson, 1979). More specifically, Danchak (1976), states that the percentage of active screen usage should not exceed 25%, and displays usually judged "good" did not exceed 15%, and Smith (1980, 1981, 1982), recommended character levels that equal 31.2% as a high density and 15.6% as a low density. Empirical studies have shown that human performance decreases with increasing display density (i.e. Burns, 1979; Dodson and Shields, 1978; Cicchinelli and Lantz, 1977). Landis, Slivka, and Jones, (1967) found that performance increased in a simple logistics game as the level of information presented increased while performance decreased in a complex reconnaissance game as information increased. They proposed that the general function relating performance and display density has an inverted U-shape, with increasing density improving performance at low levels of density but degrading it at higher levels.

Local density has been largely ignored in the guidelines, stating only that spacing helps to structure a screen. The empirical data suggests that there may be an optimal level of local density, and levels below or above optimum degrade performance, although a variety of measures, such as line spacing, separation of adjacent characters, and separation of groups, have been used to examine local density. Brown and Monk (1975), found that search time increased with higher local density, while Treisman (1982), found the opposite. However, Ringel and Hammer (1964) found the inverted U-shaped function and an optimal level with double-spaced lines.

In the area of grouping, many of the guidelines suggest that similar items be grouped together (Bailey, 1982; Cakir et al, 1980; and Galitz, 1980). The empirical data is sparse, perhaps due to the difficulty in defining "group." Treisman (1982), found that a smaller number of groups is better than a larger number of individual items for performance. Banks and Prinzmetal (1976), found that grouping is beneficial if a "key" item can be grouped by itself. Cropper and Evans (1976), recommended that a screen be designed in discrete "chunks," each of which subtends a visual angle of less than 0.088 rad (5-deg).

The major emphasis concerning layout complexity is that the user should be able to predict the location of some items on the screen, based on the location of others. The guidelines recommend a tabular format (Bailey, 1982;

NASA, 1980) and vertically aligned lists with left justification for words and alphanumeric data (Engel and Granda, 1976), while numeric data should be right-justified on the decimal point (Bailey, 1982; Galitz, 1980). The literature is largely void of relevant or notable empirical studies.

This type of review shows that while much work has been done in this area, it is still incomplete. Most likely, for all the characteristics discussed, there is an optimal level above and below which performance decreases. Further research that is more focused yet manipulates the these variables to a greater extent is needed to develop reliable standards for all alphanumeric displays.

AUDITORY INPUTTING

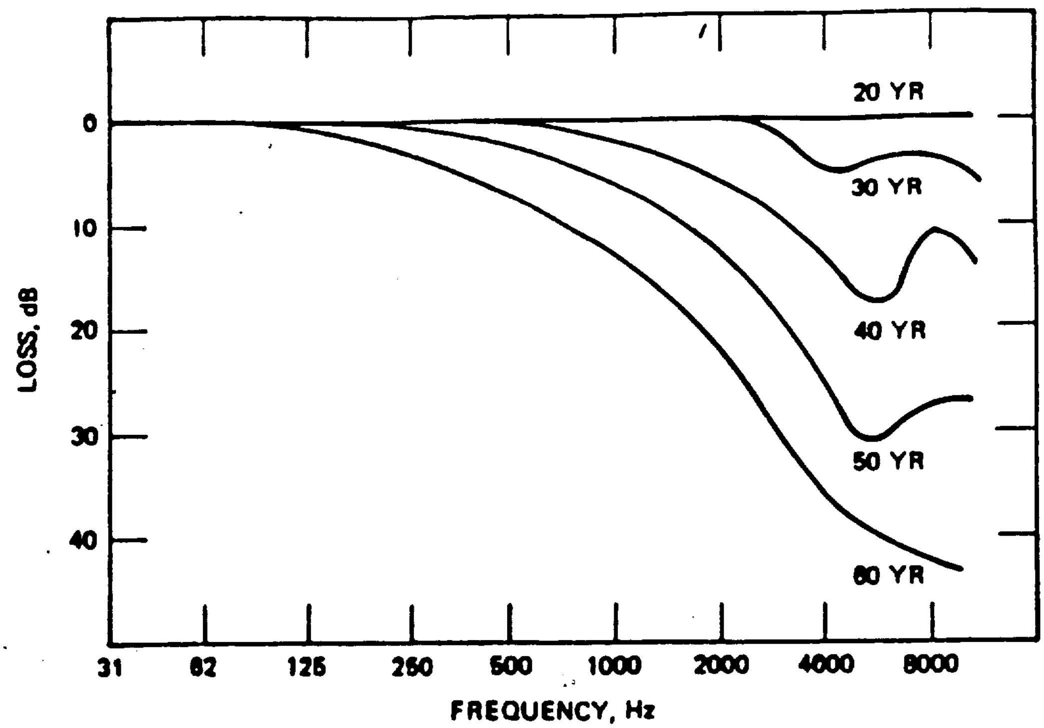
Auditory signals may be used to enhance the caution warning system in addition to providing feedback relative to various control actions the operator may perform.

Van Cott and Kincade (1972) present a comprehensive review of research on auditory perception. The review presented here will highlight only those features of auditory perception that pertain to the OMV control and display panel. The frequency, intensity and location of the signal, whether it is presented continuously or intermittently, and the signal's message.

Frequency and detection of auditory signal. Aural signals should have frequencies between 2500 and 4000 Hz and should be composed of more than one frequency for optimal performance. Peak sensitivity is in the range from 2000 to 4000 Hz, as frequencies in this range tend to sound louder than either lower of higher frequencies of the same intensity.

Since individuals may be insensitive to some frequencies, it is important to use a signal incorporating more than a single frequency. Age causes loss in the higher frequencies; consequently, a 4000 Hz upper limit appears appropriate for most people (See Figure 6).

Intensity and detection of auditory signals. It is well known in the human factors community that loudness and pitch interact and that louder sounds are more likely to be detected. For any type of auditory environment there is a threshold intensity at which a sound can be detected 50% of the time. A quite small loudness increase (as little as 3 dB) can improve detection to nearly 100%. The OMV command and control console would be expected to approximate a private business office for nominal operations, presenting the operator with a 50 dB wide band masking. The frequencies of the ambient noise is unknown, but would be expected to be mostly in the 400 to 2000 Hz range for the human voice. Office hardware, machine and air conditioning noises would have to be empirically

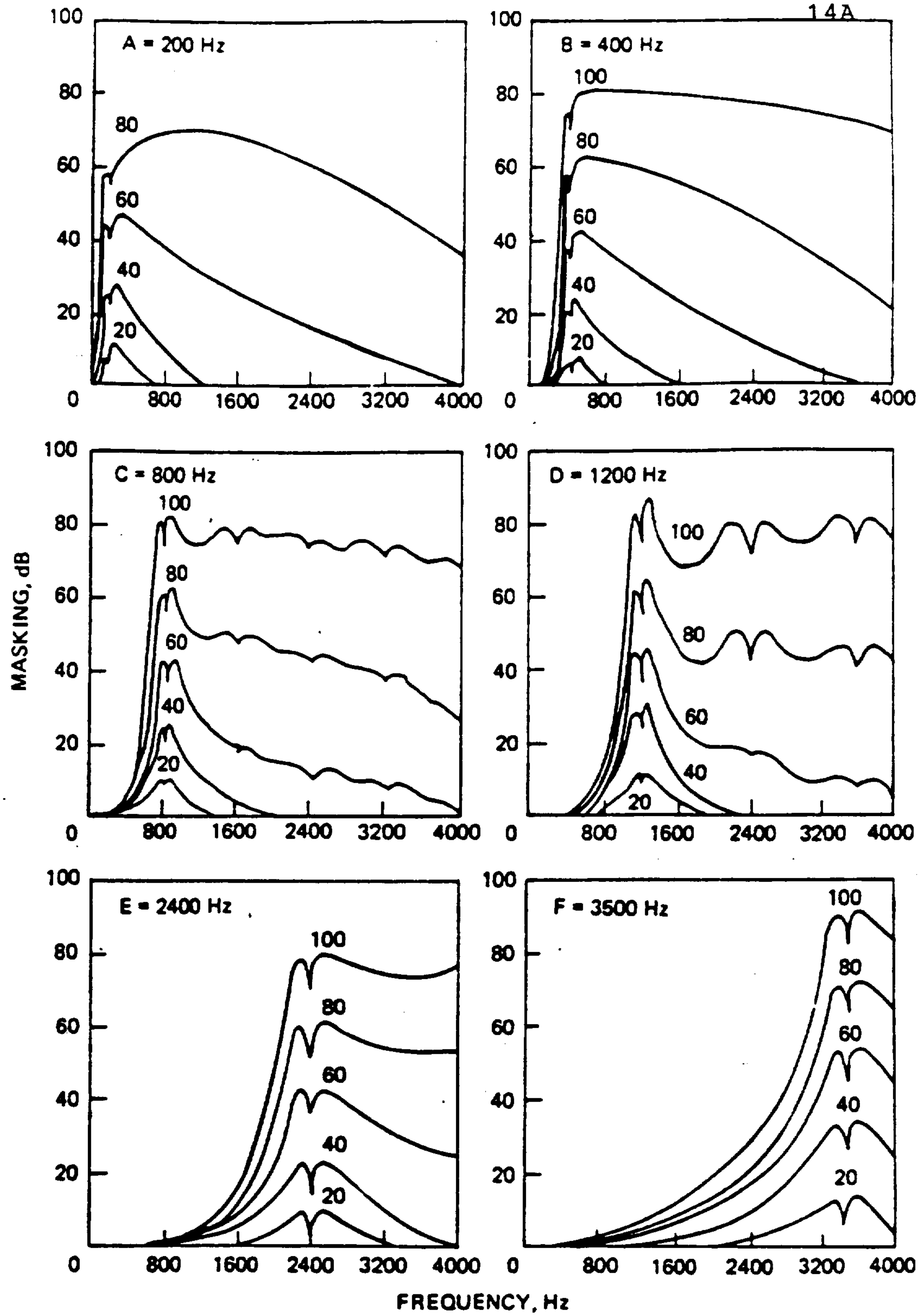


NOTE: THE AUDIOGRAM AT 20 YEARS OF AGE IS TAKEN AS A BASIS OF COMPARISON. (FROM MORGAN, 1943, AFTER BUNCH, 1929.)

Figure 6 *Progressive Loss of Sensitivity at High Frequencies With Increasing Age* determined. Wegel and Lane (1924) have provided figures relative to the masking of one tone and the delta intensity above threshold-in-quiet required to insure signal detection. The office environment approaches a wide-band ambient noise masking condition. Wide band noise does not have a uniform intensity over the frequency spectrum. The human ear can filter out noise outside a certain range around a signal. The frequency width of this range is called the critical band width and varies depending upon the frequency being used (See Figure 7). Morgan et al. (1963) indicated that the threshold of a pure tone auditory signal can be predicted if the band width of the noise near the frequency of the pure tone is known. The technique involves measuring the level of ambient noise at the auditory signal frequency. This measured frequency level is corrected for the wide-band effect by adding the 10-log value of the critical bandwidth (can be read from the left ordinate of Figure 8). The corrected level is the masked threshold for the aural signal.

In conclusion, aural display signals should exceed masked threshold by at least 15 dB; optimal signal level is halfway between masked threshold and 11 dB.

Location of sound signals and detection. Aural signals should be presented dichotically. Earphones, if worn,



NOTE: Number at top of each graph is frequency of masking tone, Number on each curve is level above threshold of masking tone.

Figure 7 *Masking One Tone by Another Tone (Wegel and Lane 1924)* should be worn on the dominant ear. Alerts should be separated from distracting signals by 90 degrees. Broad-band sound signals should be used when localization is not possible.

Research indicated that individuals have a dominant ear and messages obtained in the dominant ear are more attention provoking than messages received in the non-dominant ear (Gopher and Khaneman, 1971).

Localizing sounds is affected by the frequency of the sounds. Mills (1958) found that localization of pure tones was optimal between 3000 and 6000 Hz and was poor for tones from 1000 to 1500 Hz. Cherry (1953) found that when simultaneous but different verbal messages were being presented to both ears, the operator had no trouble separating the signal message and completely ignoring the other message.

<u>Detection of intermittent of steady state auditory signals.</u>

In general, for warning signals, intermittent aural signals should be used and cycle time should be 0.85 seconds on and 0.15 seconds off. Steady-state signals due to adaptions tend to become less noticeable after a short period of time.

<u>Detection of auditory signals and message content</u>. High priority aural signals should involve both an alerting signal and an action signal. The user's name is a highly

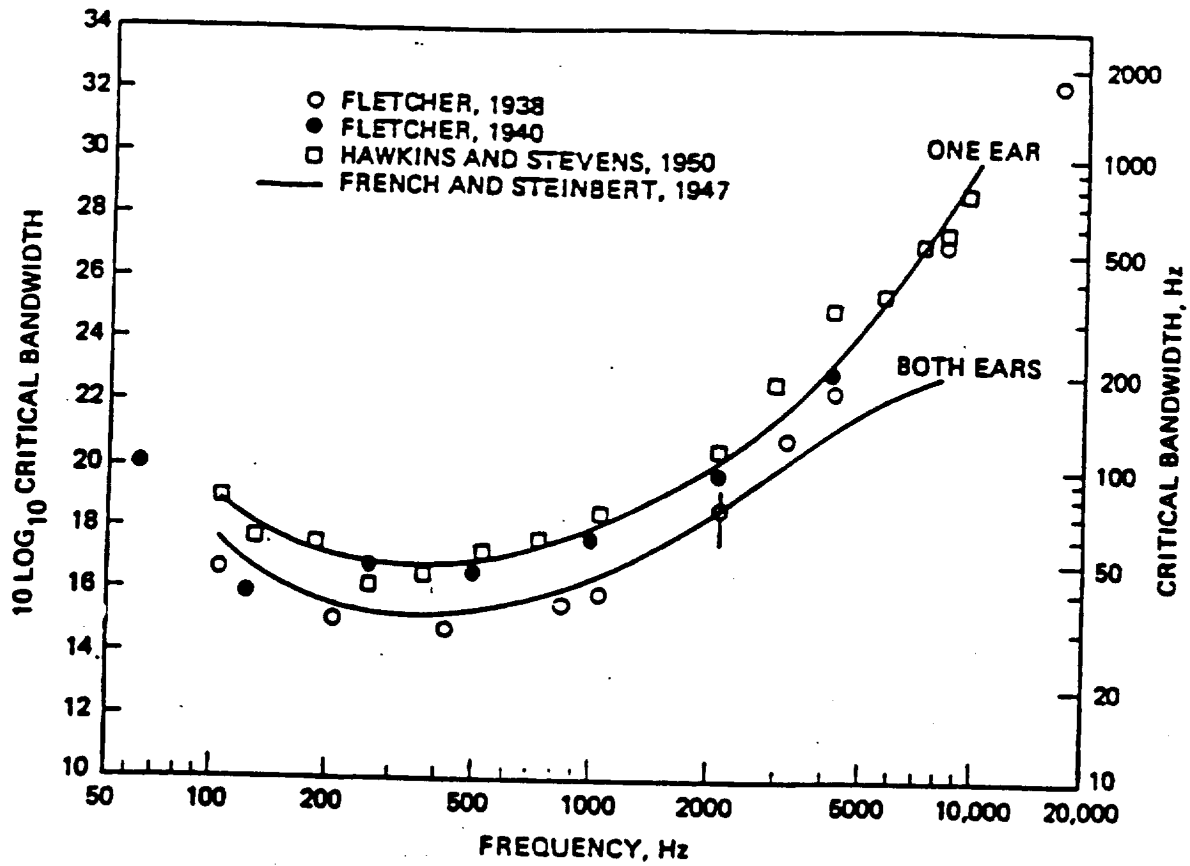


Figure 8 Critical Bandwidth of Masking in Wide Band Noise (Fletcher 1953)

attention provoking alerting signal (Howarth and Ellis, 1961; Moray, 1959; Oswald et al., 1960).

TACTILE DISPLAYS

Detection of tactile signals. Nate and Wagoner (1941) found that a steady state tactile signal was detectable as long as the stimulus was sinking into the skin. When the weighted signal stopped, the subject could no longer feel it. The skin is optimally sensitive to signals that vibrate between 200 and 300 Hz (Woodworth and Schlosberg, 1964; Van Cott and Kincade, 1972).

The amplitude of a tactile signal should correspond to the sensitivity of the area of the body stimulated. Wilski (1954) measured body region sensitivity to vibrator frequencies and found the fingers most sensitive and the buttocks least sensitive.

In terms of tactile stimulus intensity, Gescheides et al. (1968) found the practical range of intensities to be between 40 and 50 microns.

Tactile signals should not be placed on areas of the body not involved in motion (Hill et al., 1968).

In summary, tactile signals must be intermittent to be detected and the frequency of the signal should be between 200 and 300 Hz. Little systematic research has been done with tactile displays and given the lack of data a very carefully designed series of studies would be required to validate their potential use in an operational environment. Studies presented below indicate that tactile displays are disruptive to visual displays and as a result it is recommended that tactile displays be avoided.

SIMULTANEOUS VISUAL AND AUDITORY INPUTTING

Klingburg (1962) had subjects respond to a 1.5 degree visual angle similar to aircraft warning lights combined with an 88 cps auditory signal. He measured the number of signals missed each half hour. Probability of detection was significantly higher than for the same signals presented alone. These findings are consistent with other studies (e.g. Klemmer, 1958; Fidell, 1969).

The temporal sequence of the signals is important. Several studies have confirmed that simultaneous presentation of auditory and visual signals produces faster response times than presenting the signals alone (Carroll, 1973; Bertelson, 1968). Bertelson found that if the auditory signal occurs before the visual signal the subject will respond more quickly (See Figure 9).

Best response times occur when the interstimulus interval (ISI) is between 100 and 300 msec. Geblewiczowa (1963) tried longer ISIs but found that .5 sec. produced quickest response times. Kuess (1972) used two auditory signals and found reaction time inversely related to ISI

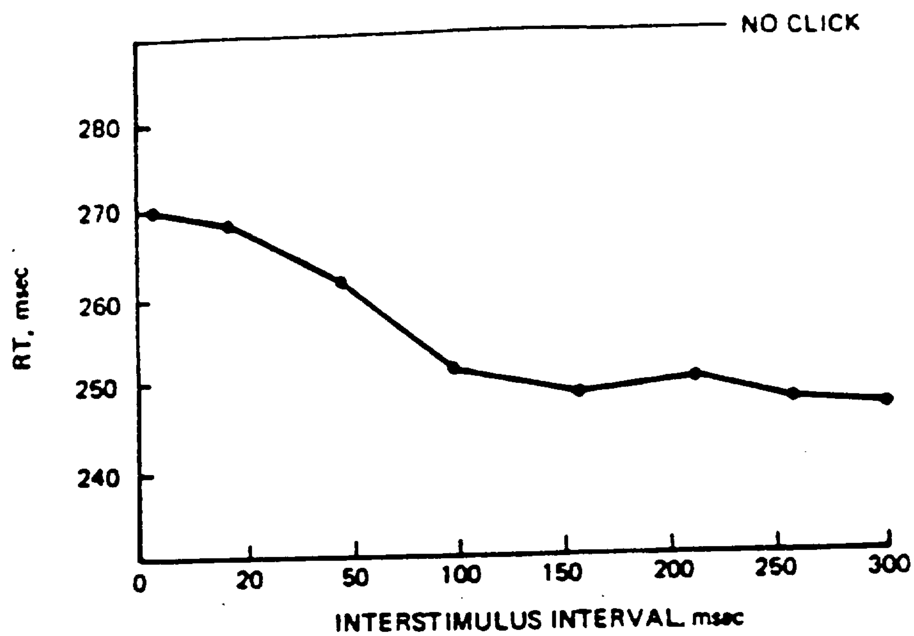


Figure 9 *Mean RT as a Function of the Interstimulus Interval (Burtelson, 1968)*

until the interval reaches 200-250 msec. (e.g. ISI less than 250 msec. produce longer reaction times).

In regard to location of the signals, Perriment (1969) found quicker responses when the light and sound signals came from the same side of the panel regardless of which side of the subject they occurred.

In summary, auditory signals presented before visual signals produce quicker responses to caution-warning signals. The interval between signals should be between .1 and .3 seconds. Also, both auditory and visual signals should come from the same side of the observer.

In providing feedback to the operator relative to control inputs, the auditory input for the translative control should emanate from the left side of the operator and should be discriminably different from the auditory feedback for the rotational hand controller feedback.

ENVIRONMENTAL FACTORS AND SIGNAL DETECTION

The general operational milieu or conditions present when the stimuli are presented can strongly influence the response of the operator. These factors include the presence of other signals or distractors, the cognitive workload imposed on the operator and his vigilant state.

A study of the information processing characteristics of human operations indicate that there is an optimal rate at which humans process information most effectively (Poulton, 1960; Rogers, 1968). Operators tend not to monitor information presented slower than the optimal rate without missing a considerable amount of data. Information presented faster than the optimal rate produces overload resulting in performance deterioration.

Cognitive task difficulty also affects operator performance. Cognitive workload generally decreases the number of signal stimuli one can process. Experimental designs evaluating cognitive workload generally require an operator to discriminate a signal from among distracting stimuli.

Distracting noises and signal detection. Generally, the closer the signal is to the noise in time and space, the slower the response. Tactile noise in most disruptive to visual signals. Bimodal signal configurations are best when noise is present and signals must be prioritized so that lower priority signals may be attenuated.

In regard to modalities signals and/or noise can be visual, auditory and/or tactile producing a 3x3 matrix.

Crawford (1962 and 1963) found that either flashing or steady state distractor lights increase detection time for a light signal. Eriksen and Hoffman (1972) exposed subjects to visual distractors as close as .5 degree of visual angle from letters used as visual signals. Other letters and block discs were distractors. When the signal and noise were similar (letters) reaction times increased. Additionally, the closer the signal and noise were in time and space the greater the reaction times.

Adams and Chambers (1962) had subjects perform visual or auditory tracking tasks. Visual and auditory tracking were degraded by auditory and visual noise, respectively. Schori (1973) had subjects perform visual, auditory and tactile tracking and at the same time monitor warning lights. Noise was either lights, white noise or painless shock. Visual signal detection was poorest in the tactile tracking condition.

Thackray and Touchstone (1989) simulated an air traffic control task that subjects performed for two hours. Subjects were required to perform two competing tasks, i.e. detect alphanumeric changes and detect two aircraft at the same altitude. The task of detecting two aircraft at the same altitude degraded over the two hour task. They concluded that the decrement was specific to stressful effects of task load on attention. These findings were consistent with Thackray and Touchstone (1985) and indicate that passively monitoring a large number of signals degrade performance, particularly in regard to attentional processes.

Laboratory studies of environmental noise are always difficult to generalize to an operational environment. However, when one looks at the OMV display panel with the various overlays of information that may be present, the potential for noise is apparent. Digital status data are presented. These data will be changing at some rate. In an emergency situation the cognitive workload produced by these (i.e. digital) data may become excessive. Add to this workload the manual tracking and docking tasks that require the use of both hands and the workload is enlarged to an even greater degree. A careful functional analysis and task analysis should reveal what information the operator actually requires in performing docking maneuvers.

Bimodal signals have been found to be either as good as or better than single-modal presentation of signals. For example, Buckner and McGrath (1961) presented subjects with a vigilance task while at the same time requiring them to attend to 24 signals. These signals were either visual, auditory or a combination of these two modalities. Detection was good for all signals, but minimum detection rates were higher for bimodal signals (89%) than for unimodal signals. In general, when attempting to detect warning signals in the presence of distracting stimuli, auditory signals are detected better than visual signals. Tactile signals may have a more disruptive effect on performance.

A warning signal should sufficiently change the sensory environment to overcome ongoing workload demand.

Holfe and Lindsay (1973) evaluated aircrew workloads, recognizing that either workload that is too heavy or too light, may degrade warning signal detection. They recognized the complexity of measuring workload concluding that subjective and physiological assessments were the best for the flight environment. Israel et al. (1980) used an event-related brain potential as a physiological method of measuring task workload. Subjects performed a simulated air-traffic-control task and measured the subject reaction time to a secondary task. They concluded that the event-related brain potential reflected differences in workload and co-varied with reaction time data.

Once again, the generalizability of a laboratory study to the operational environment is problematic. In the laboratory Isreal et al. (1980) presented subjects with a primary visual detection task and then augmented workload with a secondary auditory task. In the OMV operational environment, the operator will be presented visual, auditory and tactual inputs with dimensions such as display load, memory load, response load, etc. The utility of event-related brain potential as an index would require a parametric disaggragation of these dimensions through careful stimulation and analysis.

Conrad (1951, 1954, and 1955) had subjects respond to visual signals from four to 16 clocks. As the number of clocks increased, errors of omission increased. If a subject was responding to one signal he was twice as likely to miss another signal. When the workload was high some subjects attended to only part of the clocks, missing all signals on the other clocks by as much as 30 seconds.

Workload can be reduced by having all pointers in the same orientation for the signal. In this orientation additional signals can be added and only increased reaction by .01 second compared to 2.88 seconds for unaligned no-signal pointers.

Number of signal stimuli and the number of steps in data collection. There should be no more than nine signals for any dimension. Dimensions refer to a specific signal parameter such as frequency, brightness, location, etc. Different signals and verbal labels increase the quality of signal that can be identified (Boucek, 1977). Shower and Biddulph (1931) found that when subjects were presented single auditory signals varying in one dimension, he could identify the signals by name or response as long as that number did not exceed 7+2. These findings were confirmed by Mills and Pollack (1952).

Pollack (1954) found that total amount of information conveyed could be increased by utilizing additional dimensions. They also found that the discrimination that could be made on a single dimension decreased when other dimensions were added. The dimensions conveying the most information are visual dimensions of linear position (3.2 bits) (Hake and Garner, 1951), and hue (3.1 bits) (Eriksen, 1952). The tactile dimension of pressure is one of the poorest (1.7 bits) (Hawkes, 1961).

Visual and auditory channels have a number of dimensions for conveying information. Various visual and auditory coding systems have been developed. Conover and Kraft (1958) developed sets of colors and obviously, language is the most efficient auditory system.

Language signaling systems. In proximity operations, particularly when docking, when the operator can be expected to be under high stress, the audio-visual load on the pilot may reach saturation levels if the operator is confronted with time delay and an unstable satellite. Voice prompting and/or warning may be valuable in these situations in that the operator can evaluate the criticality of the situation without taking his eyes off the screen.

Voice signals are presented in one of two ways. First, pre-recording of human speech requires a recorded message for each warning. Implementing this type of signaling has generally been restricted to a limited number of standard signals. Second, computers can be used to control a voice synthesizer to generate pre-stored warnings and recovery procedures. Rapid access to numerous messages is possible. Obviously, however, the synthesized voice does not sound like a human voice. Simpson (1975) presented pilots and non-pilots with 16 sentence length messages via human speech or synthesized speech and found the articulation score for pilots to be equivalent whether the pilot was exposed to synthesized or human speech. She found that words in sentences were more intelligible than the exact same words presented alone. Sentences provide the operator with redundancy and context that make it possible for the operator to miss a word but make a good guess to fill in the blank. In another study, Simpson (1976) attempted to determine if messages could be shortened to further decrease response time and yet maintain adequate recognition. She presented pilots with voice-synthesized keywords and sentence-length messages in several signal-to-noise ratios. Pilots were familiarized with half the message. Monosyllabic keywords were repeated more accurately over a wider range of signal to noise ratios when words were in sentences. This finding did not hold for polysyllabic words.

In summary, it has been found that verbal signals afford the quickest response times particularly when stressed. Sentences are better than single words and the messages must not be known to the observer.

In the caution-warning context, voice messages have proved to be responded to quickest and with more precision if the message informs the operator of the appropriate corrective action in simple declarative sentences (Pollack and Tecce, 1958).

TIME FROM DETECTION TO RESPONSE

In the operational environment an operator must make the appropriate response to a detected signal. Consequently, any effective display should inform the operator of the nature of the problem and/or tell the operator how to respond. An interval of time between signal detection and response will occur and will depend on the signal, the environment and the previous experience of the operator.

Signal factors affecting time from detection to response.

Combination visual/auditory and visual/voice appear to be the most effective for complex information transfer. Voice stimuli consistently produce a faster response.

Effect of environmental factors on time from signal detection to response. Any environmental situation that increases the demands on the observer can be expected to increase time from signal detection to response (e.g. Smith, 1969). Previous experience exerts a very strong effect on operator performance. Warning and alerting signals should be consistent with the operator's expectations. Fitts and Jones (1961), in a classic human factors study, showed that the stimulus-response relationships were different in three types of aircraft (B-25, C-47, and C-82) that were flown by the same pilots. Pilots with greater familiarity with one aircraft would operate the propeller pitch control when they wanted to increase the throttle, causing loss of airspeed.

Effect of number of steps in data collection on time from detection to response. After detecting a signal the operator can respond only if he or she knows the appropriate response. If the signal does not provide adequate information on the problem the operator must search for more information so as to be able to take corrective action. This searching obviously increases the operator's workload and takes time away from other activities. Voice messages should be used to transfer high-priority information as a general rule.

Pollack and Tecce (1958) had subjects perform a tracking task with a joystick and a rudder score in terms of number of correct movements. Two banks of 12 warning signals were to be monitored and scored in terms of pressing a button under the correct warning signal. They used three different warning conditions: visual only, buzzer and visual, and voice and visual displays. The voice message told which warning signal was on.

Voice and visual, and buzzer and visual were statistically better than the visual only. Klammerling et al. (1969) had subjects fly an F-111 flight simulator and at the same time monitor the control panel. Failures were signaled by either a tone or a voice recording of the nature of the problem. Responses to the voice were 1.46 sec faster than to the tone only condition.

VIRTUAL IMAGE DISPLAYS

Virtual image displays have increasingly become a major contributor to human performance in aviation and aerospace tasks in the last two decades. They are now used so extensively that the lives of thousands of civilian and military passengers and pilots and the safety of billions of dollars of equipment is, in at least some way, dependent on them. Accordingly, research into the improvement of these vital aids has increased during the last decade.

Virtual image displays generally take the form of either, "head-up narrow-angle combining-glass presentations (HUDs)... (or) ...head-mounted projections of wide-angle sensor-generated or computer-animated imagery (HMDs) (Roscoe, 1987). HUDs are the most common type used and researched and are the type with which this paper will primarily be concerned. HUDs are achieved when visual data is, "projected on a partially silvered, partially transparent surface or 'beam splitter' directly in the ... (user's) ...forward line of sight and focused at infinity." (Sheridan, 1974). The transparent surface is generally a windscreen. The projection is collimated at infinity to insure that it is always in focus (Poulton, 1974). A pilot views collimated CRT symbology through a combiner glass as though it were overlaid on the outside world.

The image of the lens acts as an effective field stop ("porthole"), resulting in an instantaneous field of view consisting of two overlapping, circular, monocular fields, one viewed by the left eye and one by the right, with only a small portion of the field of view seen binocularly. (Gibson, 1980). The main purpose of HUDs is to allow the user to receive visual information from two sources with a minimum of eye and head movements, thereby maximizing the time spent gazing at vital information.

The most common use of the HUD is in aircraft cockpits, as currently all United States tactical fighters and helicopters are equipped with them as well as a few commercial airliners (Roscoe, 1987). However, HUDs can be employed in a variety of human/machine interfaces, such as aerospace tasks and automobile operation. They will also conceivably be increasingly used in weapons systems requiring vigilance to dual visual displays.

In the case of the pilot, the benefits of an HUD are obvious. It can provide him or her with instrument readings without requiring the head to be tilted down, a situation which can have disastrous results, considering the low reaction times which the pilot must achieve in order to survive. A large variety of information can be displayed in this manner. Horizon, altitude, attitude, and airspeed information and predictor traces can be presented to the pilot (Sheridan, 1974), and displays that provide the pilot with directions while he or she is flying low (Poulton, 1974), are examples of this variety.

It has long been known that HUDs should not try to present too much information due to possible operator confusion or vertigo (Sheridan, 1974). However, several recent reports have raised serious questions concerning possible drawbacks and safety hazards resulting from the use of HUDs. These reports concern causes that are much more difficult to pinpoint. About 30% of tactical pilots report instances of disorientation, especially when flying in and out of clouds, when using a HUD (Barnette, 1976; Newman, 1980). There are documented cases where airplanes became inverted without the awareness of the pilot (McNaughton, 1985). Pilots have reported a tendency to focus on the display rather than on the outside real-world scene (Jarvi, 1981: Norton, 1981). And most importantly, the U.S. Air Force lost 73 planes flying by reference to HUDs in clear weather due to disorientation resulting in loss of control in 19 cases or pilot misorientation resulting in controlled flight into the terrain in 54 cases (McNaughton, 1985). As a result, research into possible disadvantages of HUDs has increased.

Gibson (1980), investigated the effect of binocular disparity on HUDs, resulting from two types of system error.

HUDs are nominally collimated at infinity so that the plane of the display image is coincident with that of the outside world and keeping the image always focused. However, any inaccuracy in the distance between the cathode-ray tube (CRT) and the lens system that is used to project the image onto the transparent surface will result in the image being either in front of or beyond infinity. If the CRT is placed inside the focal length of the lens system, the virtual image is formed between infinity and the lens, while a CRT placed outside the focal length forms the virtual image beyond infinity. A second source of system error results from the fact that the focal plane of a lens is not completely flat. The CRT image moving across the focal plane must follow the curvature of the plane if the HUD is to be accurately collimated. When a flat display is positioned at the nominal focal length of a lens, some parts of the HUD may form a real image, some a virtual image, and some may be collimated. Both of these types of system errors lessen the binocular effect of the nominal HUD by causing retinal disparity for the user and alters the spatial location of the display, which in turn can lead to visual discomfort. Gibson sought to examine the tolerance of the visual system to binocular disparity resulting from deviations in collimation in HUDs.

Ten subjects, four Royal Air Force aircrew with experience with HUDs and six civilians who met RAF pilot entrance requirements with respect to vision, were used. The equipment used included a modified HUD with a 10.2 cm optic system and associated electronics. The HUD could be set to different collimation levels that would produce positive disparity, when the display is in front of infinity, or negative disparity, where the display is beyond infinity. In the first experiment reported, a basic HUD configuration of a winged aircraft symbol and horizon bars was projected against a real world background consisting of a large building with numerous window frames and vertical and horizontal features. The aircraft symbol was used as a target in an imaginary weapon aiming situation. The range of the target was -0.34 mrad. Each subject was shown the HUD set to a negative disparity of 1.74 mrad and all reported visual discomfort. Each subject then went through a series of trials where the disparity of the HUD, originally set at zero, an absolute display convergence of +0.34 mrad, was continually increased negatively until the subject reported that the visual discomfort was just perceivable. Each subject had five practice trials and 20 data trials. The results showed that the mean value of negative disparity at which any discomfort was perceived was 0.83 mrad or when the HUD is 0.83 mrad behind the target.

Gibson's second experiment was designed to examine the optimum setting for a HUD in a weapon-aiming situation, or at what point in space the display should be projected for best results. The same HUD used in the first experiment was employed. The subjects were asked to adjust the extent of the limitation of the HUD until the display could be optimally viewed against the outside world with no visual discomfort. Fifty percent of the trials started with the display in front of the target and 50% were behind it. Before each trial, a random amount of positive or negative disparity was introduced by the experimenter. The results showed that a mean setting of +0.72 mrad, i.e. the optimum viewing position was found to be at a positive viewing disparity of 0.38 mrad. Nine of the ten subjects set the display to a positive disparity.

Gibson's third experiment investigated the relationship between an individual's threshold for parallax and the onset of viewing discomfort. The reasoning behind this investigation is that the essential cause of the discomfort is the presence of binocular or retinal disparity. The perception of parallax is the appreciation of some amount of disparity that is above threshold level. Therefore, a correlation between parallax and viewing discomfort could be present. Those people with a low threshold for parallax would be expected to report viewing discomfort at smaller values of negative disparity than those with a high threshold level. Using the same HUD, but two fewer subjects, the presence of parallax was conveyed to the subjects by introducing 0.58 mrad of negative disparity and asking them to view the position of the display against the target with each eye alternately by covering one eye at a time with a hand. The subjects were allowed to change eyes as many times as needed. They were instructed to report the point at which they could just determine the presence of parallax between the HUD and the outside world target. Sixteen trials were recorded for each subject. The mean threshold value for parallax detection was found to be 0.23 mrad. A Spearman correlation procedure was used to examine the relationship between the parallax threshold and the onset of visual discomfort. A positive correlation ($r_s = +0.52$, $r < 0.1$) was found, but was not significant at the 5% level.

Gibson's three experiments investigated the tolerance of the human visual system to differing levels of binocular disparity in HUDs. The first experiment indicated that subjects experience a sense of discomfort when viewing a HUD presented at a negative disparity, or is focused beyond infinity. This discomfort may be the result of conflicting depth cues that will be discussed in more detail later. The second experiment showed that subjects preferred a positive disparity set at 0.72 mrad. The third experiment found a correlation between a low threshold for parallax and the early onset of visual discomfort but it was not statistically significant.

One factor suspected to be a primary cause for the difficulties with HUDs is misaccommodation of the eyes. It has been shown that human eyes do not automatically focus at optical infinity when viewing collimated images but are allowed to lapse inward toward their dark focus, or resting accommodation distance, at about an arm's length on average (Hull, Gill, and Roscoe, 1982; Iavecchia, Iavecchia, and Roscoe, 1987; Norman and Ehrlich, 1986; Randle, Roscoe, and Pettit, 1980), and the bold symbology of a typical HUD does not require sharp focusing for legibility. Thus the eyes are not required to focus at infinity, which has been held to be one of the major advantages of a HUD. The result is that most pilots are not able to concurrently view both the collimated symbology and the distant objects beyond in the real world without constant focus shifting and the associated losses in distant acuity and veridical spatial orientation (Iavecchia, Iavecchia, and Roscoe, 1988). The perceptual consequence of positive misaccommodation is a shrinkage in apparent visual size of the entire scene, causing distant objects to be judged farther away than they are, and objects below the pilot's line of sight to appear higher than it truly is relative to the horizon (Roscoe, 1987). This type of misperception can result in only slight differences in intended and actual position, but can also be fatal in some situations.

Iavecchia, Iavecchia, and Roscoe (1988) conducted two experiments designed to determine how HUD symbols affect eye focus, the extent of refocusing required to respond properly to both the outside world and the display symbology, and the individual differences in the effect when dark foci are taken into account. The main issue behind their investigation is the tendency of eye accommodation to remain at or return to its resting position despite the acuity demand of a visual task.

The two experiments were conducted outdoors in daylight using two rooftops separated by a distance of 182 m. On one rooftop were the subject and experimenter, a HUD built by Marconi Avionics for the A-4M light attack aircraft, its associated electronics, an optometer to measure accommodation distance, and a microprocessor to control timing and data collection. On the second rooftop was mounted a pentagonal carousel with each face capable of displaying digits of a different size. In addition, a sheet of linen cloth was mounted on a frame and place in the HUDs's immediate field of view to simulate the view from inside a cloud, and sun shields were used to improve numeral visibility in full sunlight. Luminance of the scoreboard numerals of each size was approximately 6850 cd/m^2.

Ten subjects selected randomly from NADC personnel and confirmed to have at least 20/20 uncorrected binocular vision were used. Experiment 1 was a single-factor repeated measures design. Head-up display background texture was the independent variable, with HUD symbology appearing either against a simulated cloud background or against a distant terrain background. Accommodation was the dependent variable. Control conditions included focus responses to each background while looking through the HUD but with no symbols displayed, focus response to the HUD symbols displayed in darkness, and dark focus, or resting accommodation.

Experiment 2 was a repeated-measures design with two factors, location of targets (two levels) and target acuity demand (five levels). Targets were located either on the carousel only or on both the HUD and carousel simultaneously. Control conditions included focus response to the terrain background while looking through the HUD with no targets visible, focus response to a HUD digit displayed in darkness, and the dark focus.

The subjects performed two tasks. A series of three digits between 0 and 9 was randomly presented in the center of the HUD, with a stimulus duration of 800 ms and an interstimulus interval of 300 ms. The first task was to add the second and third digits and to press one of two right hand response buttons denoting whether the sum was odd or even. Subjects were not required to respond rapidly. During the last 400 ms of the 800 ms duration of the third HUD digit, the optometer bars flashed. The subjects' second task was to push one of three left hand response buttons to indicate whether the central bar segment was to the left or right or centered with respect to the upper and lower bar segments. In the condition where both the carousel and HUD digits were presented simultaneously, the subject was to add the third digit in each of the two series and indicate whether the sum was odd or even. The odd/even responses insured that the subjects were in fact reading the carousel and HUD, and the optometer response was used to obtain accommodation responses until the refractive state of the subject's eyes to the HUD targets could be measured.

In the area of overall experimental effects, it was found that whether in the dark or in a cloud, the presence of the HUD symbology had little effect on focal responses, with small differences among the variables. From these results, the authors concluded that, "By itself a collimated virtual image does not draw accommodation to optical infinity." Using HUD symbology, focus shifted outward only 55 cm from the average dark focus of 149 cm, $t(9) = 1.25$, $p = 0.246$, and only 27 cm from the average response of 152 cm to the cloud alone, $t(9) = 0.829$, $p = 0.434$. The average response to the cloud alone was almost identical to the average dark focus.

However, when the HUD was turned on and used against an outside terrain background or a terrain plus carousel background, focal responses lapsed inward by large and statistically significant amounts. The lapse between the terrain only and the terrain plus HUD was from 33 m to 6 m, $t(9) = 3.07$, $p = 0.013$, and the values for the terrain plus carousel were optical infinity and 4 m, $t(9) = 6.98$, $p = 0.0001$.

Some interesting results were found when pretest, midtest, and posttest measures of each subject's dark focus, or resting eye accommodation, were compared for both experiments. Very small differences in measured dark foci between Experiments 1 and 2 were found, and could have easily been due to chance, $F(1,9) = 1.71$, $p < 0.22$. It was found that the dark focus shifted outward for most of the subjects during each experiment, but drifted back inward by posttest, particularly during Experiment 2, which lasted one and one-half hours. The authors attribute this effect to the fact that eye accommodation is a function of the sympathetic and parasympathetic branches of the autonomic nervous system, and that fatigue and a decrease in adrenalin production caused the dark focus to return to pretest levels.

It was also indicated that an individual's dark focus is highly predictive of all other focus measures, regardless of viewing conditions. In this study, knowing a subject's dark focus accounted for 88% of the variability observed in all other focus measures. It was also observed that some subjects never focused at optical infinity, despite their normal visual acuity. Subjects with dark foci closer than about 3 m (0.33 D) never focused all the way outward to 0 D, and one with a dark focus of -2.86 D never had his focus come inside -1.75 D, regardless of the difficulty of the acuity task at optical infinity. Only two subjects frequently focused at or slightly beyond optical infinity. When the HUD was used, the subject's accommodation tended to lapse inward. This indicated that focus to the HUD plus real targets is not the same as focus to real targets alone. The key points to be summed up from this study is that where the eye focuses for any stimulus is greatly dependent on the individual's dark focus, and that because most people have a dark focus closer than optical infinity, viewing collimated targets will not result in infinity focus for most persons, even those with normal visual acuity.

Norman and Ehrlich (1986) studied visual accommodation in virtual image displays used for target detection and recognition. They sought to investigate how the interposition of a HUD between a pilot's eyes and the outside world affects his or her ability to detect and recognize distant targets and how this might interact with the accommodative mechanism. Twelve emmetropic males were required to detect and recognize small targets presented at infinity on a blank background while simultaneously monitoring an HUD and three red light emitting diode digits presented on a combiner. The HUD was presented at four optical distances, collimated (at infinity, 0.0 D), beyond infinity (-0.5), and two nearer distances (2.0 and 0.5 D). Measurements of accommodation were obtained from each subject in the dark to assess their dark focus, and also while monitoring the HUD at each of the four optical distances.

The subjects were told that one of two targets would appear fairly regularly at different distances from the center of the HUD along the arms of an imaginary X. At the same time, the three LED digits would change in unison, and sometimes all three digits would be identical. The subject's task was to detect the target, indicating this by moving a response stick (RS) in one of four directions to show where the detection occurred, recognize the target, indicating this by pressing one of two buttons on the RS, and simultaneously monitor the digits for an identical threesome, indicating this by pressing a third button on the RS. The subjects were told that accuracy was more important than speed, and that the target and recognition tasks were more important than the digit monitoring task. They were not informed that the HUD would be at varying optical distances. The subjects were payed a standard fee for participation, but also received a bonus based on their level of performance.

After the instructions were presented, the subject spent a short period of rest in the dark, followed by the first measurement of their dark focus. They were then given a block of practice trials in which the HUD was presented at infinity with the digits changing at a slow rate. Feedback was provided for target detection and/or recognition errors and errors of omission. Eight experimental blocks lasting 15 minutes each with no feedback given then followed. At the middle of each block, the target tasks were halted while the digit monitoring task continued and measurements of accommodation to the digits were taken, twice at each of the four optical distances. The dark focus was also measured at the beginning and end of a ten minute rest period between the fourth and fifth experimental blocks and at the end of the experiment. An experimental block consisted of 72 slide exposures, 48 blanks, and one each of the 24 targets (2 types in 12 positions) in random orders for individual subjects. Each optical distance was presented once before and once after the rest break in counterbalanced order across subjects.

The results indicated that the optical distance of the HUD affected the subject's ability to detect and recognize small targets presented at infinity. When the HUD was set to 2.0 D, response times were 15% to 18% slower than at the other three distances, and error rates were considerably higher. The differences in performance when using the other three distances were small. The authors stated that while some might use this finding to estimate that collimation errors of ± 0.5 D do not affect target recognition and detection, they feel that this would be premature due to the small number and young age of the subjects, and some interaction effects. A combined measure of accommodation and dark focus was taken. The subjects were ranked from one to 12 in both categories. The two ranks were summed for each subject, and then the 12 subjects were separated into two groups. The subjects with the far dark foci and/or larger accommodations were labeled COMB-1 and the subjects with the near dark foci and/or small accommodation ranges were labeled COMB-2. The subjects in COMB-1 performed best when the HUD was at an optical distance of infinity (0.0 D) or beyond, while COMB-2 performed best at an optical distance of 0.5 D or at infinity. The attributes possessed by COMB-1 are superior for the type of tasks conducted, as they produced faster detection and recognition responses, and fewer recognition errors and errors of omission, to significant levels. It was found that for the three optical distances around infinity (0.5 D to -0.5 D), the accommodation measures accounted for 55% of the variance in the performance. In addition, despite the usual assumption that viewing a collimated display causes the eye to accommodate to infinity, most of the subjects in this study did not.

As much of the research summarized so far has shown, there are certain individual visual differences that affect the effectiveness of virtual image displays. While proposals to overcome these deficiencies through hardware improvements have been put forth and will be discussed later, some efforts to improve the human component of the system should be noted. Techniques to improve eye accommodation have been put forth for most of this century, and are again being considered, given the problems with

VIDs. Roscoe and Couchman (1987), investigated the use of volitional focus control to improve visual performance. This study did not attempt to retrain myopic eyes to see better as many have, but attempted to train already good eyes to see better. The major goals involved were to convert volitional focus control and far-point extension into improvements in operational visual performance and to train pilots to refocus their eyes in anticipation of the presence of distant targets thereby overcoming the misaccommodation that occurs with collimated virtual images. Two methods were used in Roscoe's and Couchman's attempts, and they produced differing results.

Six Air Force ROTC students with 20/20 vision or better participated in training using an infrared tracking optometer (IRO) and variable focus stimulator (VFS), that had been used successfully by Randle (1985) to induce remissions of acquired behavioral myopia in teenagers. The IRO is a servo-controlled error-nulling instrument that continuously monitors the state of focus of the human eye and indicates relative dioptric changes over a scale of -4 D to 6 D. The VFS is a relay instrument that easily presents visual stimuli by the use of back-illuminated photographic slides or a CRT and can image its aperture plane precisely in the eye's entrance-pupil plane, providing a true artificial pupil that obviates changes in retinal image size. Because the aperture to be imaged is distal to the eye, it can be any size or shape, can be opened and closed electromechanically, can be used to control target intensity, and can use a pinhole aperture that provides such a large depth of field that the target is always clear and does not require accommodation, which means that the eye either regresses to the resting position or responds to the trainee's volitional control.

The testing and training procedures took place in three phases. In the initial phases, the subjects were tested to determine that they met the visual standards and oriented to the IRO and VFS by the presentation of all target types, starting one diopter inward and proceeding inward and then outward. In the second phase, before and after each session, dark focus, near point and far point measures were taken. The actual training consisted of nine procedures that were used in an ad-lib manner depending on how the individual trainee was progressing over the sessions. The procedures were (1) square-wave tracking, to demonstrate the muscular feel of accommodating to different distances as the focus demand was shifted; (2) open-loop constant-tone control at dark focus, to demonstrate that the tendency for the accommodation level to drift away from its initial dark focus could be controlled; (3) open-loop constant tone control at far point, to prepare the subject for far-point extension training; (4) holding constant tone against varying target demands, to develop self-confidence in volitional focus control; (5) far/near point exercise without stimulus, to give practice in dynamic as opposed to static focus control; (6) four-level stepwise tone matching, to refine the ability to control accommodation ability; (7) far-point extension, to "pull" the far-point outward in 0.2 D steps to improve distant acuity and contrast sensitivity; (8) far-point extension with square wave stimuli, to develop the ciliary muscle while shifting the VFS's 3-D square-wave program outward in 0.2 D steps; and (9) flash target resolution at far point, to exercise volitional control to improve distant target detection by overcoming the tendency for accommodation to lapse toward the dark focus in empty-field conditions. Auditory biofeedback generated by two tone-generators linked to the position feedback signals from the IRO and VFS were used in the training. The third phase consisted of repeating the tests administered in the initial phase.

While the primary training method just described used an extremely complicated and expensive piece of equipment, an alternate training method was used for three subjects that was much simpler. This method depended on improving volitional focus control by realigning the light bars of a polarized vernier optometer (PVO) set at focal distances other than the individual's dark focus. A PVO projects one target (a short, horizontal bar segment polarized in one direction) through one half of the eye's pupil, and a second target (a pair of cross-polarized horizontal bars, one to the left and one to the right of the central bar) through the other half of the pupil. Varying the focal distance of the target's light source relative to that of the eye causes the two targets to be displaced vertically relative to each other. When the bar segments are in vernier alignment to form a continuous bar, the focal distance of the target source coincides with the distance at which the eye is focused. Moving the PVO source inward from the eye's momentary focal distance causes the central bar to be displaced upward from the outlying bars, and moving it outward from the eye's focal distance causes the central bar to be displayed downward. Manipulation of the optical distance of the target light box indicates both the amount and direction of the misfocus of the eye to the trainee.

The training of the three additional subjects began with the optical distance of the PVO stimulus displaced inward about 0.5 D, which resulted in a misalignment of the light bars. The subject was instructed to realign the bars by thinking of looking at something close.

After this was accomplished, the PVO stimulus was then displaced farther inward until the subject could no longer align the bars, at which point the PVO focal distance was moved outward about 0.5 D from the subject's dark focus, and the subject was instructed to think of looking at something far away and again realign the bars. After this was accomplished, the PVO stimulus would again be moved outward until realignment could not be accomplished.

The results were somewhat disappointing to the experimenters. Both methods improved the visual performance of the subjects, but the three subjects who were given the much simpler and less expensive training method outperformed all six subjects who used the complex IRO/VFS instrument. Also discouraging was the fact that improvement was generally slight, and fell far short of approaching the 99th percentile of visual ability, which was a hope of the experimenters. As with other visual studies discussed, individual differences were readily apparent in all measures.

In view of the studies discussed, the future of VIDs appears to be in doubt. Despite the obvious benefit of allowing a pilot or other operator of a system that requires visual monitoring of discrete tasks to view both with a minimum of head and eye movements, the potential drawbacks of uncollimated displays and the fact that few people focus at infinity anyway have caused questions to arise. Given the number of lives and amount of money that are affected by VIDs, improvements are necessary.

Several recommendations have been put forth and some are already being implemented. First, the specifications for HUDs must be strictly followed by designers. HUDs should be limited to critical data, symbols should be bright enough and contrast sufficient to be legible under all expected ambient conditions, they should have a minimum field of view of 350 mrad (20^{o}) in the vertical plane and 490 mrad (28^{o}) in the horizontal plane, and symbols should have a minimum line width of 1.7 minutes, and preferably should be 3.4 ± 0.7 minutes, (MIL-STD-1472C).

Secondly, care must be taken to insure that the display is collimated at infinity, and especially is not beyond infinity, (Iavecchia et al, 1988). However, it should be noted that, "... we go through life not noticing that most of what we see is badly out of focus." (Iavecchia et al, 1988). Perhaps this is what has made VIDs as widespread as they are.

Finally, individual differences among the users of VIDs should be taken into account when they are designed. The individual's level of accommodation and dark focus are extremely predictive of his or her effectiveness with VIDs. Stringent testing should be used to select the best qualified users. However, research into VIDs that can be adjusted by the user for maximum efficiency can prevent the pool of users from becoming too small. (Norman and Erlich, 1986; Iavecchia et al, 1988). While some would seek to overcome the individual differences through training of the sort done by Roscoe and Couchman, (1987), it is unlikely that this is a viable option given the current state of technology and resources in the field.

Roscoe (1987), feels that due to the limitations of the VID and the human visual system, the long-range prognosis for VIDs is not good. He does feel that ways must be found to live with them, as they are currently vital to our tactical aircraft, but that future research should concentrate on more easily optimized direct-view displays of sufficient angular size to provide the needed fields of view with appropriate magnification.

The OMV control panel will consist of a number (up to 96) switches. The status of these switches can be signaled by their position, lights, and displayed messages. The display monitor can be use for tracking, translation, and docking. Various overlays will be superimposed on the screen at different stages of the mission as appropriate. Mostly digital information is currently planned to be presented on these overlays. Auditory feedback will be presented to the operator when he makes inputs into either of the hand controllers. Finally, a caution warning system will be included to alert the operator to trouble. Various research findings are presented above with implications for specific design decisions as well as for a display philosophy. It is not possible to extrapolate from what are predominately laboratory research findings or from years of irrelevant albeit related experience in aeronautics aerospace to the actual OMV display and controls. It is a new system with unique features and problems. Commercial aviation and NASA have evolved an effective model for systems design (i.e. functional analysis, search for relevant literature, task analyses, iterative simulations, operator input, etc.). Such an approach is hierarchical and iterative with ever increasing degrees of precision and sophistication. Once the operator requirements are determined, then state-of-the-art graphics and display technology can be implemented to simplify the operator's task and reduce the likelihood of error without losing precision performance.

HUMAN PERFORMANCE

For optimal performance of the man-machine system, it is extremely important to make careful ergonomic considerations for the design, selection, and arrangement of all control devices. In the operational OMV environment, in proximity procedures in particular, there is a time envelope involved in which the operator can make proper responses. Fitts and Jones (1947) point out that poorly designed controls alone can lead to inefficiency and breakdown in the man-machine system. Also, with the OMV being a remotely operated vehicle, a set of unique, problematic circumstances exist. The pilot of a remotely operated vehicle is deprived of the tactile feedback that is available to the pilot that is actually inside the flying vehicle. The pilot of a remotely operated vehicle cannot "feel" rate indication during precision movements such as du_ing landing and tracking of targets, producing inferior performance to that of the flying pilot (Hirsch, 1977). The great distances characteristic of space operations cause unavoidable delays in information transmission (Ferrell, 1966). Time delays between the operator's control action and the effect of this action exist in addition to the dynamic lags characteristic of the electromechanical apparatus (Ferrell, 1965). Time delays do not have to degrade operator performance, however, they can if not compensated for. In all probability OMV missions will be non-repeatable, leaving little or no room for errors. These factors make it important that the controls and displays of the OMV Ground Control Console (GCC) be designed such that optimal operator performance is facilitated.

With these thoughts in mind, it is the purpose of this section to review relevant control literature, apply those findings to the TRW design in order to point out possible advantages and disadvantages, and also to move toward enhancing the present design of the OMV GCC.

Hand Controllers. The primary way that information will be transferred from the operator at the GCC to the OMV system will be via two hand controllers. It is our understanding that these hand controllers will be a bang-bang system with isometric control. Bang-bang manual controls can be particularly applicable in spacecraft attitude control systems where there is a need to slew rapidly at first, and to be set precisely thereafter (Schmidtke, 1984). From the time the operator is given control of the OMV, nominally 1000 feet from the target, until within 150 feet from the target, slewing can be done rapidly. During proximity operations precise adjustments must be made. Consequently a bang-bang system would seem particularly suitable for the OMV.

A bang-bang strategy involves placing a control, such as a joystick, to one extreme and then rapidly moving it to another extreme. In that there is not time to exhibit the acceleration tendencies, the system moves at a constant rate. This strategy has been found to be useful because it employs a human's natural tendencies when moving hands and arms (Eberts, 1987).

Bang-bang control dynamics. Wierrwille (1984) studied design parameters for bang-bang controls. He noted that such a study was needed in that he only found one reference (Few, 1966) in which the dynamics were not varied.

In this study the control device consisted of a set of four pushbuttons on the points of a square with the square oriented such as to appear as a "diamond". The display consisted of an EAI-580 hybrid computer generated output spot displayed in x-y coordinates on a 21 inch oscilloscope. When the operator pushed the top button, the display spot moved upward, and correspondingly for the other buttons. Each subject's task was to position the display spot, using one of nine dynamics settings, so that it resided at the center (target area) of the oscilloscope screen. Subjects were alerted to the beginning of a trial by an audio tone. Upon hearing the tone the subject's task was to move the spot to the center of the screen as rapidly as possible. The trial ended when the spot was within the target area for one second.

The dynamics used in this two axis study were assumed to have the form

$$F=Mx\ +Dx$$

where F represented the constant force applied when one of the control buttons was depressed, x was the position of the output, M was the equivalent mass, and D was the equivalent viscous friction of the system. In the rewritten transfer function form

$$\frac{X(S)}{U(S)} = \frac{F/D}{S(1+\frac{S}{D/M})}$$

where $U(S)=1/s$ for a step input, F/D was the system gain and D/M was the system corner frequency in radians per second.

Results of this study are plotted in Figure 10. Numerals I and II represent the two optimal design regions. In region I system gain is high and the system corner frequency is low. In region II system gain is low

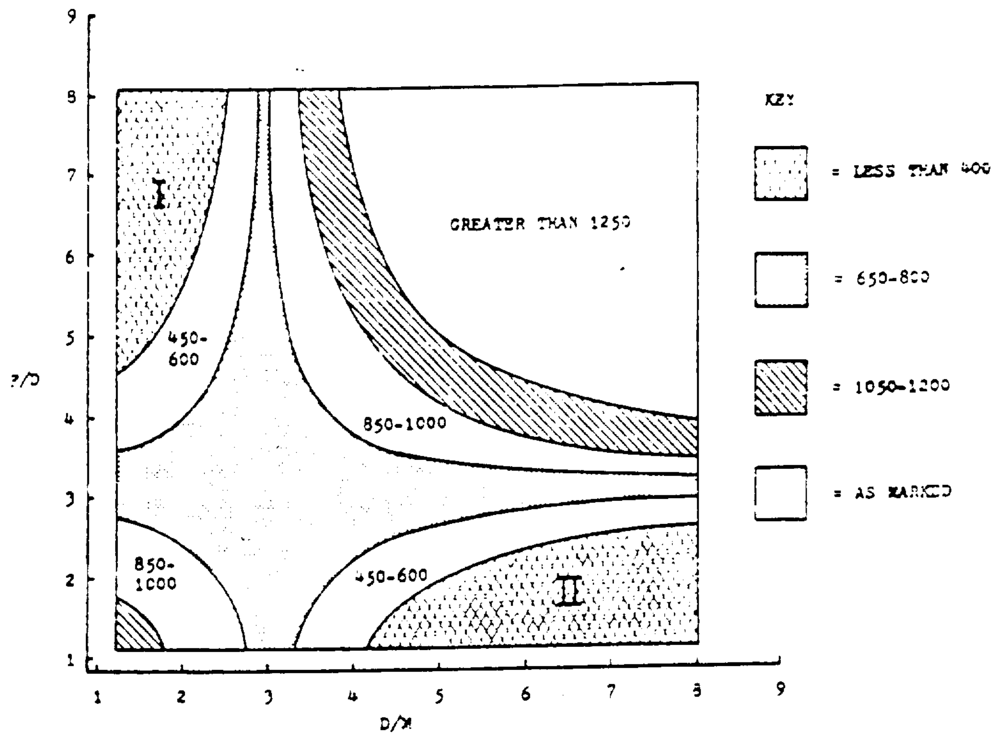


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Figure 10 *Scores Shown by Regions of the Response Surface (Wierwille, 1984)* and the corner frequency is high.

It was concluded that practical problems in control design and manual control parameter selection have not been adequately investigated; however, clear cut optimum gain was determined.

The possible drawbacks of using a bang-bang system. The dynamics of a bang-bang system are extremely complex. Mass and friction can cause speed build-ups, forcing the operator to compensate by making estimations in guiding the output to the desired final value. Another drawback is the there is little existing literature on bang-bang systems so the problems in control design and manual control parameters may not have been adequately examined (Wierrwille, 1984).

In conclusion, a bang-bang system seems to be an acceptable choice for the OMV, given the slewing requirements. However, experimental literature on this type of control system is almost non-existent. In this light designers are cautioned that care needs to be taken that proper tests and simulations have been carried out before implementing bang-bang type controls in the OMV system.

Operator workload. Kramer et al. (1987) described mental workload as the cost of performing one task in terms of a reduction in the capacity to perform additional tasks, given that the two overlap in resource demands. Resource demands have been divided into three dichotomous dimensions: perceptual/cognitive and response, verbal and spacial, and auditory and visual.

Currently, TRW plans to use two hand controllers: one for translation and the other for acceleration. Klapp et al. (1987) had subjects perform visually guided pursuit tracking with the right hand while giving simultaneous discrete left-handed responses to auditory tones. It was found that hesitations occurred associated with the left-handed secondary task. These hesitations generalized across mechanical devices and muscular actions used in tracking. This cessation of one response when another is required can obviously have degrading effects on tracking performance.

In the operational OMV environment, the pilot must attend to the two hand controllers and the pushbutton switches, while at the same time monitoring the video displays. This engages all resources, thus constituting a high mental workload. One way in which the workload could be lessened is by integrating the two hand controllers into a single hand controller. TRW documents specify that the GCC can accommodate a single six degrees of freedom controller. A plan to combine the two controllers was discussed in Rogers (1988). He suggested that "acceleration or translation could be controlled by forward, backward, right, or left movement. Rotational commands could be performed by tilting the hand controller forward or backward (pitch), tilting the hand controller left to right (roll), or twisting the hand controller right or left (yaw)" (p.16). This plan is recommended in that during the final docking, fine adjustments would be made with acceleration control, consequently, translational control movements would be at a minimum. Both functions could be controlled with one hand controller without causing interference. This plan would free the left hand to perform switch activation/ deactivation as needed to make precision docking maneuvers. With two hand controllers, one would have to be released while operating the switched. This interruption of control operation could result in tracking performance degradation.

Another possible source contributing to high workload could be the number of switches to be included on the OMV GCC. It is stated that the control panel can accommodate 96 pushbutton switches. Discussions suggest that only a third of this number might actually be included. This is still a high number of switches to maintain control over. Activation/deactivation of many of these switches require the operator to perform gross motor movements that could result in operator fatigue and distract him from tracking performance.

In conclusion, there is concern that the number of hand controllers and pushbutton switches included in the current GCC configuration may elevate pilot workload to an unacceptable level. It is recommended that steps be taken toward integrating the hand controllers and reducing the number of pushbutton switches. It is believed that these actions would have the effect of decreasing workload.

One of the major tasks that will be carried out by the OMV operator is tracking. Tracking refers to the adaptive process whereby the operator readjusts responses to a set of conditions and to a controlled element (Osborne, 1982). The main elements in tracking are input and output. Input refers to the information that the operator receives from the controlled element or target. Output refers to the operator's response to the input via a control mechanism. The input to the system, therefore, specifies the desired output of the system (Osborne, 1982; Poulton, 1972). In order for the operator to respond to a system's input, the operator must be able to perceive the information. There are two types of display modes that are commonly used to present information to the operator about the system's status. These two types are the compensatory display mode and the pursuit display mode. The pursuit display mode is recommended for incorporation into the OMV system.

The pursuit display mode as presented in research. In the pursuit mode the target position and the controlled element position are presented, making it possible for the operator to immediately perceive the error signal as the difference between the two positions (Salvendy, 1987). The operator can readily determine whether the error was produced by target movement or by the controlled system's movement. Pursuit displays also make it possible for the operator to anticipate future target states and, subsequently, plan future action. It is advisable to use pursuit displays when output is complex and a high rate of movement is involved (Osborne, 1982). Evidence suggests that pursuit displays almost always produce the best tracking performance (Salvendy, 1987).

Jaeger et al. (1980) used a compensatory display to investigate predictor operators in manual control systems.

The investigators then used the results to compare with similar experiments involving pursuit displays. Tracking performance was found to be generally better with pursuit displays when pursuit phase curves were compared with compensatory phase curves.

Because evidence suggested that a superior performance resulted from higher percentages of "pursuitedness," Briggs and Rockway (1966) conducted a study to determine if percentage of "pursuitedness" influenced learning as well as performance, or if the effect of pursuit percentage influenced performance level primarily.

In this study subjects trained under one of five display conditions, with differing percentages of the pursuit component of the tracking display (0%, 25%, 50%, 75%, and 100%). The subjects tracked in a one-dimensional lag-free (positional) control task with a five inch CRT provided as the tracking display. Subjects in each of the five test conditions were divided into two groups. After training, one of each pair of groups transferred to the 100% pursuit display while the other group transferred to the 100% compensatory display.

It was concluded that increasing levels of pursuitedness produced significantly superior tracking performance but had little or no differential effect on learning. Effect on performance, however, was not linear. Performance difference between 0% and 25% pursuit condition was greater than between 25 and 100%. Major gains in performance over that with a pure compensatory display can be obtained with a display of relatively little (25%) pursuit component. Further increments in persuitedness can result in more improvement, but gains become relatively less as a pure pursuit condition is approached.

Tatro and Roscoe (1986) had subjects perform 30-s climbing to the right flight task to test the effects of eight factors on pilot performance. Test results concerning display modes demonstrated that along-course tracking error was reduced by 19% when a combination of 50% vehicle-referenced compensatory and 50% target-referenced compensatory was employed. This combination tracking mode had the effect of a quasi-pursuit presentation. Tatro and Roscoe defined the pursuit display as "one that presents movements of a vehicle (or cursor) independent of the position and movement of some target symbol" (p.116). One drawback to a pursuit display mode is that both symbols can position themselves near one edge of the display, depriving the pilot of seeing the big picture. Trying to solve this problem by logarithmic scaling can cause sensitivity near the display's center and insensitivity near the edges. The quasi-pursuit presentation has the advantages of a pursuit display without the drawbacks. In the 50/50 mode the vehicle symbol and the target symbol are positioned relative to the center and are displaced proportionally from the center in opposite directions to indicate magnitude and direction of error. This presents information in an integrated fashion, allowing the pilot to see the big picture as well as tracking indications at the center of the display.

The pursuit display mode as potentially applicable to the OMV system. From the literature that was reviewed concerning compensatory and pursuit display modes, it seems that the two modes reside on a continuum rather than being mutually exclusive of each other. With this in mind, it could be beneficial to use the 50/50 combination tracking mode as presented in Tatro and Roscoe (1986) to allow for the most strategic and integrated display information. In this manner the OMV operator can readily perceive tracking information without losing any of the events that might occur on other portions of the display. During proximity maneuvers the operator needs to be immediately able to discern whether tracking error is being produced by the movement of a target or by the OMV's movement. With a pursuit display, immediate perception can be obtained. Reduction in tracking error and a more optimal OMV mission are the potential results. Figure 11 represents the elements to be included in a pursuit presentation.

Time Delay. Control system time lags occur when there is a delay in the effect of the operator's response upon the controlled system. A transmission time lag continuously delays the effect of the operator's response in constant time intervals (Poulton, 1974). This is a type of lag that occurs in the OMV system.

Time delay is virtually inherent in any man-machine system and consists of a lag in any system as well as human reaction time (McCormick, 1964). Wulfeck (1973) stated that the more complex and difficult a manual control task, the greater the number of inaccuracies in system response. He also offered that to maximize system response accuracy, it is necessary to compensate for lags characteristic of both control dynamics and human performance. Without compensation, the system will be annoyingly oscillatory at best or fatally unstable at

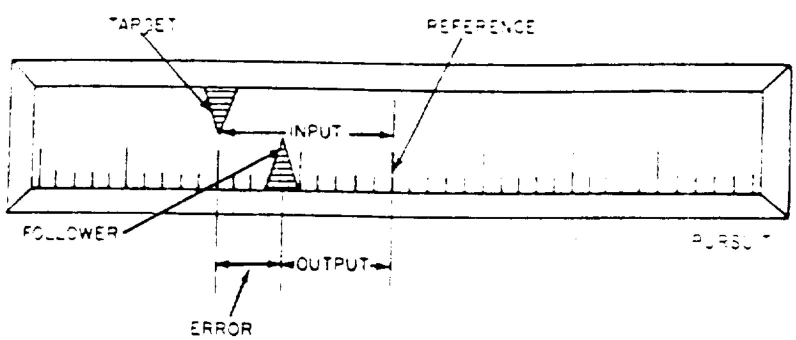

Figure 11 *Information Displayed on a Pursuit Display (Oborne, 1982)*

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worst.

Compensating for time delay. Ferrel (1965) studied the effects on the performance of both simple and complex tasks of inserting transmission delay between the operator's control action and the indication of control action. Subjects in this investigation were required to operate a remote hand to grasp a small block. Test conditions were; 1) no delay, 2) open loop, 3) delay. Subjects worked with one of three delay conditions (1.0, 2.1, and 3.2 seconds). In the simple task subjects were scored with an error if the block was moved before it was grasped. More error conditions were included in the complex task.

Results showed that all but one of the subjects developed a move and wait strategy to compensate for the time delay. Completion time was found to be a linear function of delay.

It was found that, if only visual feedback was provided, complex and accurate manipulations were possible in spite of delay. Accuracy could be obtained at the expense of time by the operator performing the task in a series of open-loop actions, each followed by a pause of one-loop-delay time for correct feedback. This study used a remote manipulator that reproduced the operator's hand position.

The authors believed that the move and wait strategy would be developed to cope with delay in on-off or with rate controlled manipulators, but adequate determination of the effect of delay on these systems must be done.

Ferrell (1966) focused on the operation of a master-slave manipulator in which the movements of the operator's hand are reproduced by the remote hand and the forces on the remote hand are reflected back to the operator's hand. The effects of delay of force feedback were observed. In this lab experiment subjects were instructed to use a move-and-wait strategy or a continuous motion strategy for positioning the remote "hand" to test the effectiveness of these strategies. In order to test the two strategies, each was measured under two conditions. The first condition was object contact. In the move-and-wait strategy, the subject was required to make successive moves and wait until contact was obtained. Using the continuous movement strategy, subjects were required to make control movement slow enough that the object would not be displaced beyond the tolerance in one delay time after stopping.

The second condition under which the two strategies were tested was spring loading. Spring loading the remote finger allowed the force transmitted to the operator's hand to be proportional to the distance from a null position (1.5, 3.0, 4.5, or 6 inches to the right of the starting position). The operator was instructed to move the remote hand to the null position as fast as possible. Failure to achieve the required tolerance was indicated by movement of the control following release. Under this condition the move-and-wait strategy consisted of moving immediately to the best estimate of the null position, waiting a delay until the feedback forces stopped changing. This process was repeated until the the force was zero. The continuous movement strategy consisted of movement at a constant velocity until the force became zero, reversing the motion and moving back at the same velocity for one delay time, and then stopping and waiting to see if the force became zero.

It was demonstrated that delays in force feedback caused a sufficiently large feedback gain resulting in instability under both conditions. The authors suggested that reducing feedback gain would not be the best way to avoid this problem because it would result in a loss of sensitivity. A more effective strategy for overcoming the stability problem was indicated to be the use of alternative displays of the feedback force.

Starr (1980) expressed that transmission time delay in the communication channel of a manual control system degrades performance by preventing the human operator from immediately seeing the results of his actions. He was concerned that the move-and-wait strategy was not as effectively usable as Farrell (1965) had demonstrated. Starr thought that a rate control mode might be more effective with time delay. His study was conducted in order to compare master-slave and rate control of a manipulator using four time delays (0.0, 0.33, 1.0, and 3.0 seconds).

The NASA-Ames arm was used as the master-slave control and a six degree-of-freedom isometric joystick was used as the rate control. Subjects performed a peg transfer task to compare these two control modes.

Results demonstrated that rate control was superior to master-slave control when high degrees of accuracy in dealing with time delay were required. It was expressed that the results of this test were applicable only to the NASA-Ames manipulator system, however, the effectiveness of rate control in time-delayed manipulation that was shown should not be overlooked.

The effects of time delay specific to the OMV system are not known at this time. It has been demonstrated that transmission time delay in remote systems can be compensated for in the laboratory setting by using certain strategies or by using different control modes. The generalizability of these tests to the complex nature of the OMV system must be approached cautiously. The importance of simulation cannot be over emphasized in the investigation of effects of time delay. As noted before, time delay is inherent in any man-machine system. In any case, delays must be compensated for or performance degradation will be the result.

Predictor displays as compensation for delays. Whether compensated by pilot, by controls and displays, or by combinations of these, the purpose is to stabilize control of the flight vehicle. For systems requiring manual control predictor displays have been shown to be uniquely capable of achieving control precision (Wulfeck, 1973). Predictor displays are largely experimental, but promising results have been found (Hutchingson, 1981). The predictor display presents estimates of future position relative to future desired position. These estimates are usually presented in the context of present position (Jenson, 1981). All presentations are integrated into the same display for direct comparison by the operator (Roscoe et al., 1981).

In the OMV environment the pilot will be provided with two displays that will present information about the system. Speed and accuracy in reading incoming information will be only half the battle. Much of the time he will have to mentally translate or computate what he sees to make predictions about the appropriate actions to take. According to Bernotat and Widlok (1966), mental prediction is relatively inaccurate especially when the different components are given in separate displays. Simon and Roscoe (1956) demonstrated the efficiency of analogue displays that provide predictor cues to the operator. Subjects were presented with display information intended to represent an aircraft's present altitude, the predicted altitude after one minute, and the final altitude to be reached. Subjects were presented with one of four types of display: 1) a vertical(strip) display with three pointers; 2) a circular (dial) display with three pointers similar to a three point altimeter; 3) three separate five digit counters; and 4) three separate circular, single pointer displays.

Given this information subjects had to decide:

1. whether they were diving, climbing or flying level

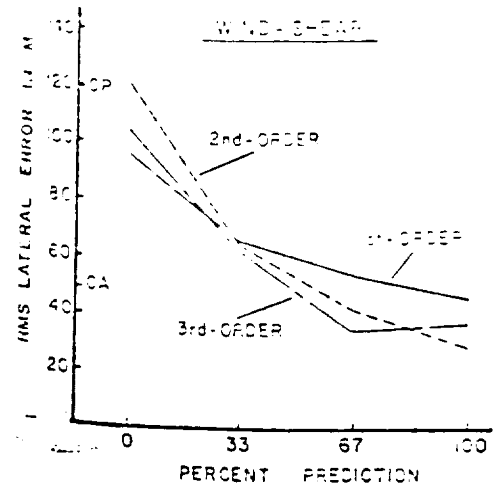

Figure 12 *Average RMS Lateral Errors in Meters as a Function of Four Proportions of Prediction and Quickening for Three Levels of Computational on the Wind-Shear Segment (Jenson, 1981)*

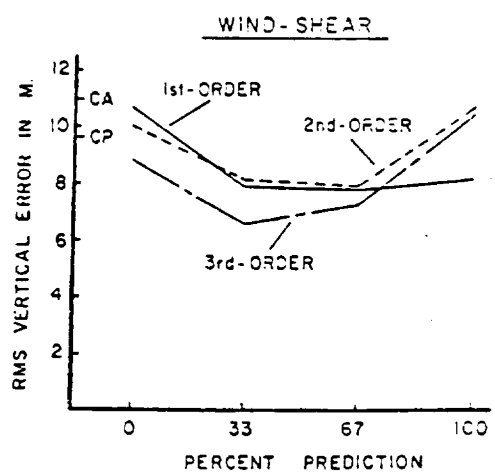

Figure 13 *Average RMS Vertical Errors in Meters as a Function of the Proportions of Prediction and Quickening for Three Levels of Computational Order on the Wind-Shear Segment (Jenson, 1981)*

2. in order to reach and/or maintain their final altitude, whether they should climb, dive, or continue flying level
3. if they should climb or dive, whether they should increase, decrease, or maintain their present rate
4. whether they should eject.

Results showed the lowest average time to complete the task when using the vertical display (56.3 sec), next was the combined circular display (64.2 sec), third the digital display (74.6 sec), and fourth, the separated circular display (79.7 sec). The most errors occurred with the digital displays (7%) and the least errors occurred with the vertical display (3%). Arguments were given that the reason for the poor performance in the digital prediction condition was because of the lack of a spacial point of reference. The vertical display condition provided the operator with the most integrated source of information.

Jenson (1981) conducted an empirical study of the relationships among various proportions of pursuit/prediction and compensatory/quickening with first- second-, and third-order predicting equations. Pilots in this study flew simulated curved landing approaches under four different wind-shear conditions using each of 18 displays. The 18 displays tested represented the parametric combinations of first-, second-, and third-order predictive flightpath algorithms and four ratios of pursuit/prediction versus compensatory/quickening, four hybrid display configurations, a zero-order or contact analogue display, and a conventional cross-pointer display as a control condition. No prediction or quickening was included in the control condition. In the 100% quickened display condition, neither of the symbols moved. The movement of the background, consisting of the contact analog and the desired flightpath, was advanced in accordance with the particular computational algorithm. The distance between the fixed airplane symbol and the desired location and orientation of the background was to be nulled. In the 100% predictor condition, an estimated future state (the moving predictor symbol) in the context of present and future desired system states were presented. The separation of predicted states from the desired states changed the task to a form of pursuit steering. The pursuit steering task is one of moving the predictor symbol to match the desired future position in the background scene. Intermediate display configurations between pure compensatory/quickening and pure pursuit/prediction were obtained by causing the airplane symbol and the background to move toward each other in proportion to the amount specified by the condition. For example, in a 33% pursuit and 67% compensatory configuration, the predictor moved 33% of the error distance, and the background advanced to the proper position to make up the remaining 67% of the distance. Results of percent of prediction versus computational order are show in Figures 12 and 13.

Findings of this study supported that lateral error on the curved approach task is reduced with increasing proportions of prediction and higher orders of computation. It was found that the greatest difference in lateral performance along the percent prediction dimension occurred between the 0% and the 33% pursuit/prediction conditions. The author indicated that improvements in lateral performance at the 67 and 100% levels suggested that longer prediction spans are useful in improving lateral performance, especially if coefficients for all predictor terms are optimized separately for horizontal and vertical control. It was also suggested that predictor displays could reduce operator workload and reduce the chance for gross motor error.

Prediction spans and control stick assumptions. Kennedy et al. (1975) designed a study for the purpose of investigating the effects on control performance of three

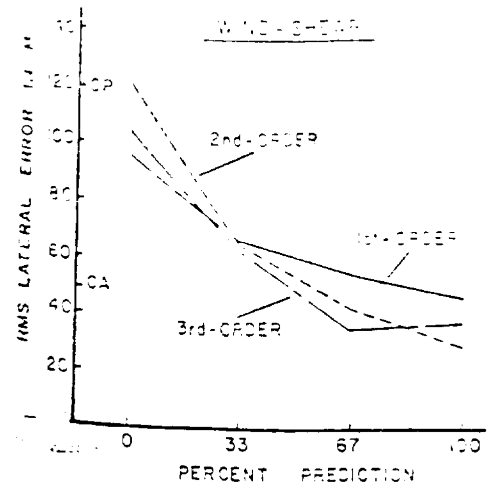

Figure 12 Average RMS Lateral Errors in Meters as a Function of Four Proportions of Prediction and Quickening for Three Levels of Computational on the Wind-Shear Segment (Jenson, 1981)

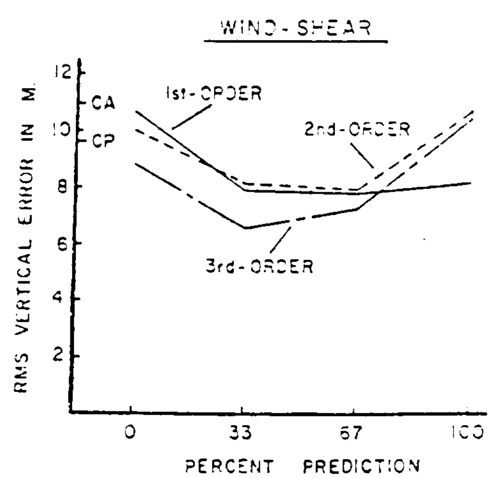

Figure 13 Average RMS Vertical Errors in Meters as a Function of the Proportions of Prediction and Quickening for Three Levels of Computational Order on the Wind-Shear Segment (Jenson, 1981)

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prediction spans (10, 20, and 30 seconds) and three control stick assumptions (the stick returns to null within 0, 1, or 3 seconds). Subjects performed a simulated F-4 approach landing which they attempted to depart from a horizontal flight and assume and maintain a trajectory along an ideal glidescope within acceptable speed boundaries to one foot from touchdown. Pilots were provided with a fast-time model predictor display (PD). Figure 14 represents the manner in which predictor information was presented to the pilot.

Results indicated that prediction spans ranging from 10 to 30 seconds, and stick assumptions from 0 to 3 seconds, facilitated performance of experienced pilots. Figure 15 presents the results of all experimental conditions. It was also indicated that a clear relationship between prediction span and control performance existed for the inexperienced pilots (i.e. the longer the prediction span, the better the performance). As far as stick assumption, human control lags from 0 to 3 seconds were completely overpowered by the overall accuracy of predictors.

In a second experiment Kennedy et al. (1975) tested to determine whether the previously indicated advantages of

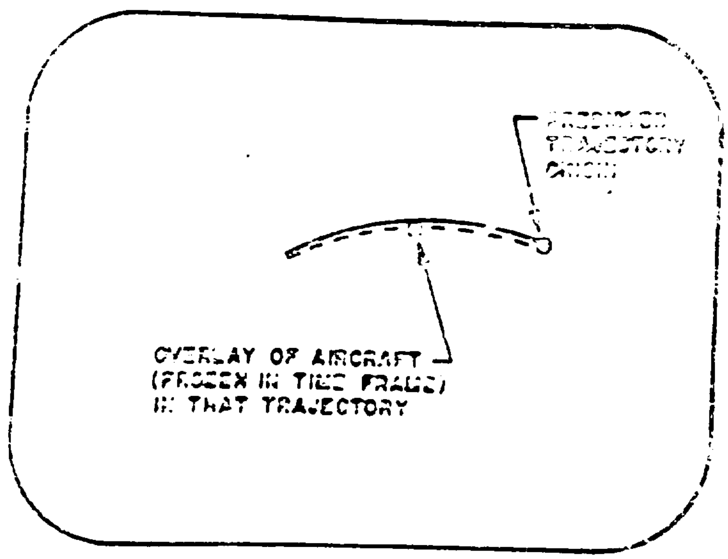
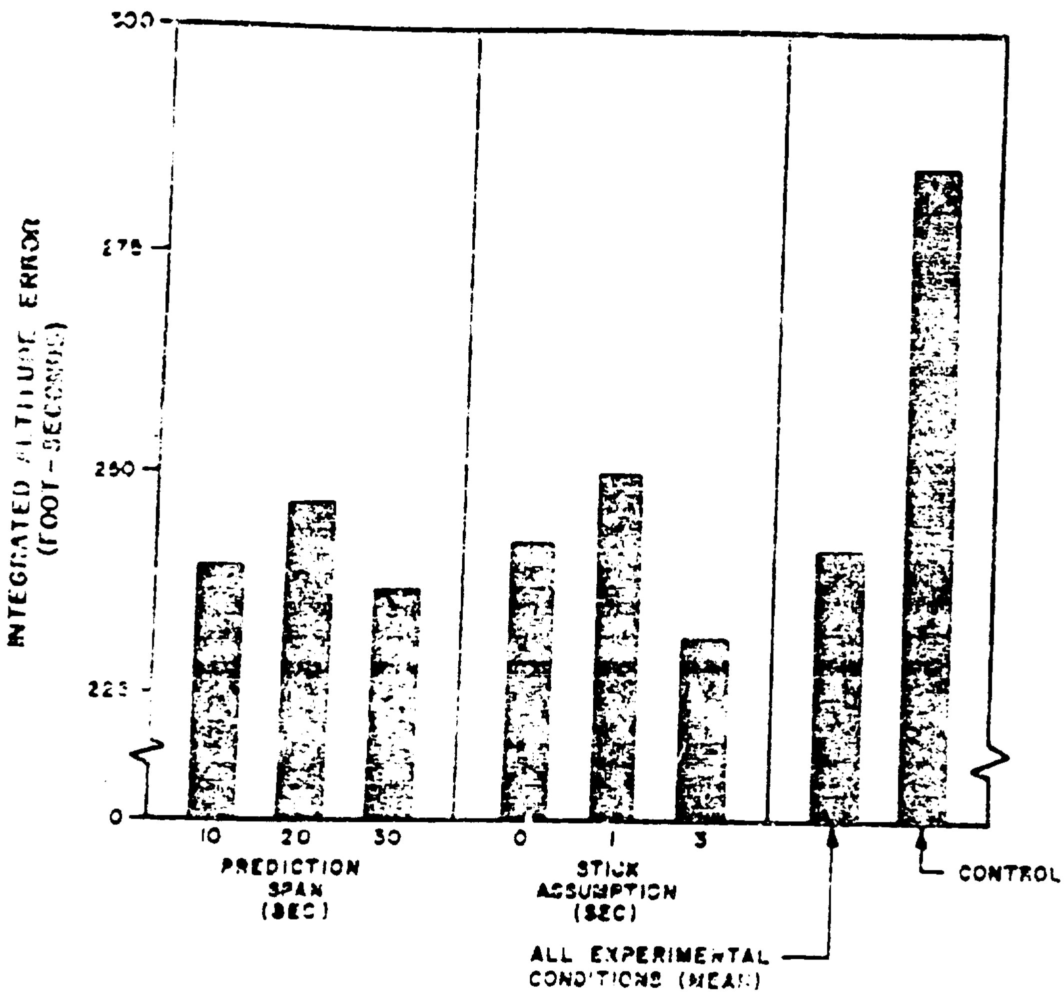


Figure 14 *Predicted Trajectory of a T-37 Aircraft, Side-Looking View, as the Pilot Views the Trajectory on the Predictor Display's CRT (Kennedy, et. al., 1975)*



NOTE. Graph also Shows contrast between the Control Condition and the Mean Score for all experimental conditions.

Figure 15 *Effects of Prediction Spans and Stick Assumptions on Tracking Error (Kennedy, et. al., 1975)*

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using a predictor display could also be demonstrated for a group of aviators who flew daily but were not experienced in the F-4 aircraft.

Subjects in this experiment had to perform a simulated night carrier landing approach using one of three display modes. The three display modes were baseline (TV), glidescope tunnel and predictor display.

The baseline (TV) display was basically a TV image of a model aircraft carrier moving through a corridor. The glidescope tunnel display consisted of a series of receding rectangles presenting glidescope deviation information. Proper location for a safe recovery was indicated when the "tunnel" was seen as a series of regular, centered rectangles converging on the center of the display. The predictor display was similar to the tunnel, except the time dimension was superimposed by the addition of a predicted flight path. The path element appearing nearest the glidescope, and the furthest path element showed the predicted deviation at 30 seconds into the future.

Performance was measured as departures in heading, azimuth, and sink rate from a 3.5-degree glidescope with the desired impact point being the Number 3 wire approximately 1/16 of a mile from the ramp (Figure 16).

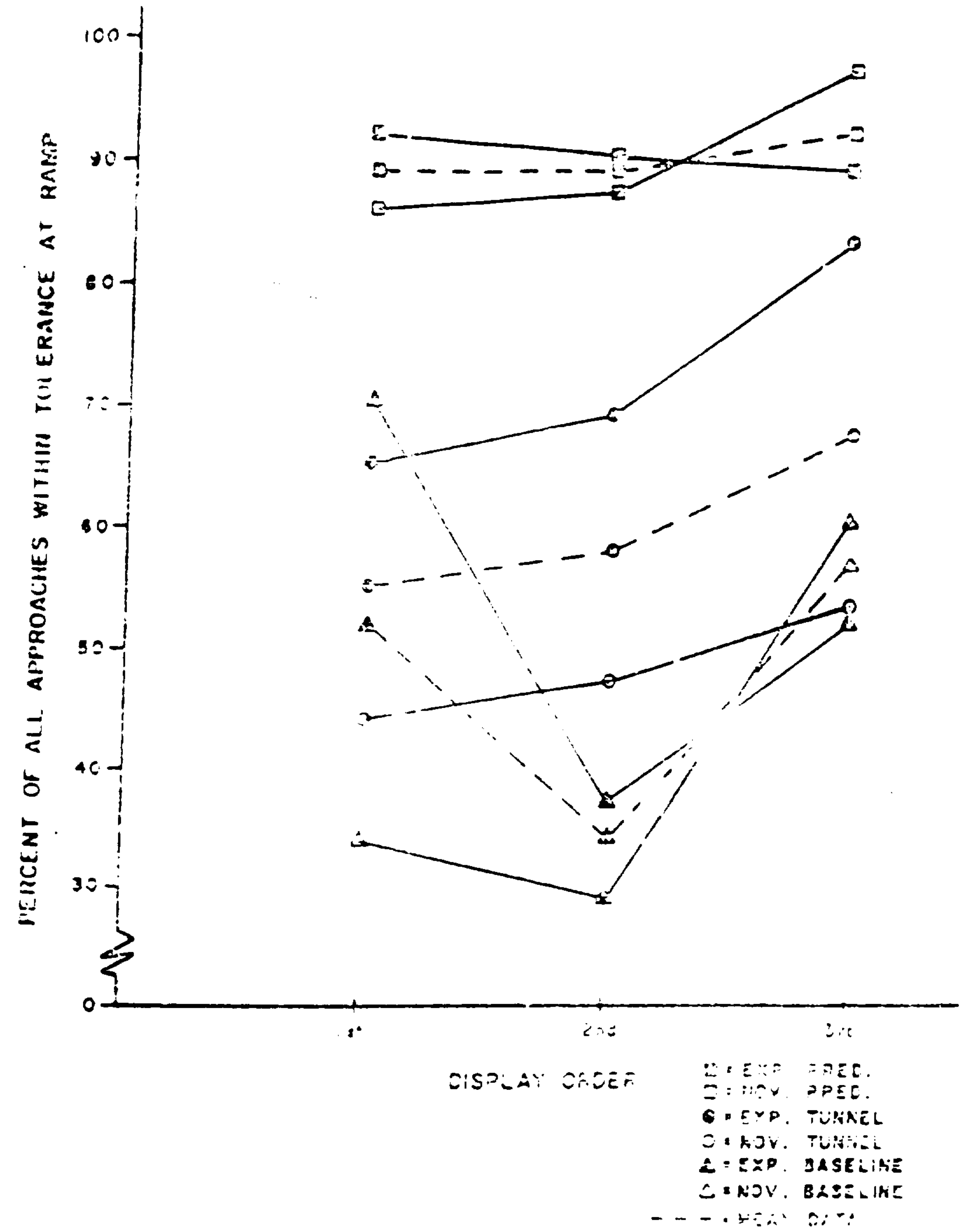

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Figure 16 *Simulated Landing Performance Data as a Function of Display Order (Kennedy, et. al., 1975)*

The results of this second experiment cross-validated the first experiment by showing superior performance in a F-4 predictor display simulated landing using pilots that were inexperienced in flying F-4 type aircraft.

In conclusion, experiments I and II demonstrated the superiority of predictor displays in flight simulation. The authors described the predictor display as a powerful tool for human manual control that has the potential of relieving the pilot of performing complex computations of vehicle dynamics. The authors also believe the applicability of predictor displays to military vehicle control systems, as well as others, to be potentially promising.

There are other studies that have found prediction to be useful, and some of these will be briefly mentioned. Poulton (1972) found that tests using vertical take-off and landing aircraft showed a deviation from the course of 2.70 degrees with a prediction and 7.92 degrees without prediction. Roscoe et al. (1981) pointed out the importance of prediction in complex control tasks and indicated that findings consistently point toward the superiority of predictor displays over conventional displays.

Prediction as it is applicable to the OMV system. The ability to predict could be very important to the OMV operator. As mentioned previously, OMV missions may not be repeatable. Therefore, if the operator is able to be shown what the result of a movement will be before he makes it, he will be better prepared for the mission. During proximity operations an operator needs to be able to anticipate the future state of the flight vehicle given a present control movement. An unanticipated control event could result in an unsuccessful dock.

A predictor display configuration suggested for use in the OMV should consist of three main elements: (1) the present path of the vehicle, (2) the predicted flight vector, and (3) the target.

Figure 17 represents a conceptualization of a predictor display that could be superimposed on the OMV video monitor during the docking phase. The present flight path consists of a guidance arrow on an airport runway. The predicted flight vector is a guidance arrow of a different color that is generated when a control movement is made. The predicted flight vector is created given the present path of the OMV so that the two arrows will converge at the predicted future position of the OMV.

In the case of a rotating target, an added graphic

Predictor Display (Stable target)

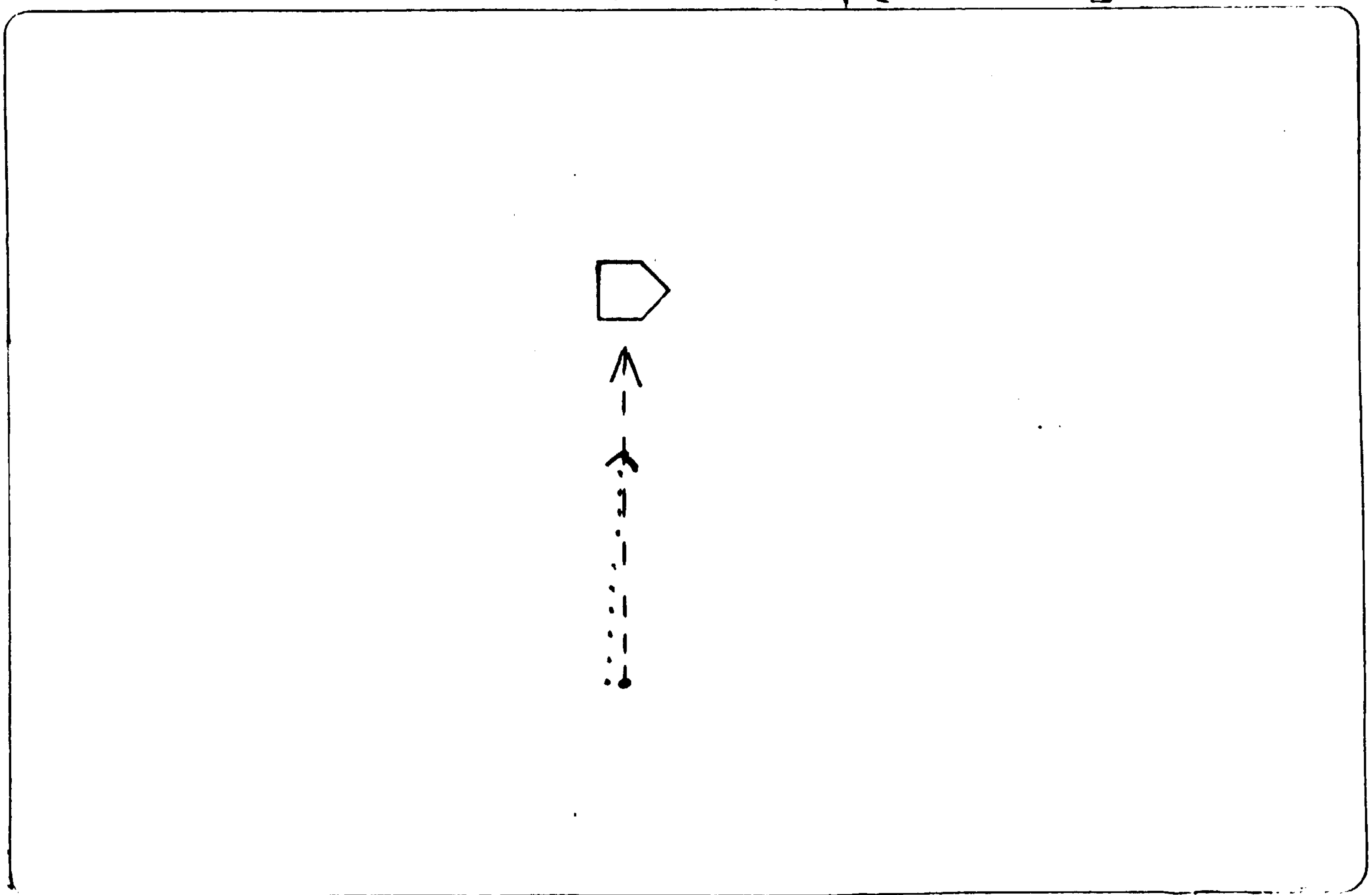

Figure 17

- - - - - Present Path

. . . . Predicted Vector

• origin

will be necessary. Figure 18 represents the position of the OMV relative to the position of the target in freeze frame. In this manner the operator could make a control movement and this movement would be projected so that he could see what the OMV's position would be within three feet of the target. The projected position could remain in freeze frame for five seconds before it disappeared so that the operator could see whether or not the OMV would be in the desired docking range.

This brings up the issue of what the best strategy would be for manual acquisition of a rotating target. Basically, acquisition could be accomplished in one of two ways: (1) by rotating in sync with the target and then moving in closer to dock, or (2) by moving in close and then starting to rotate in sync with the target until a desirable docking position is achieved. Simulation is the only way to determine the best strategy for acquiring an unstable or rotating target. Given the importance of this crucial issue, the need for simulation cannot be over emphasized.

In conclusion, although prediction is largely experimental, promising results arise from existing research. No mention of using a predictor display has yet been made by TRW. It is strongly recommended that some

Predictor Display (unstable target)

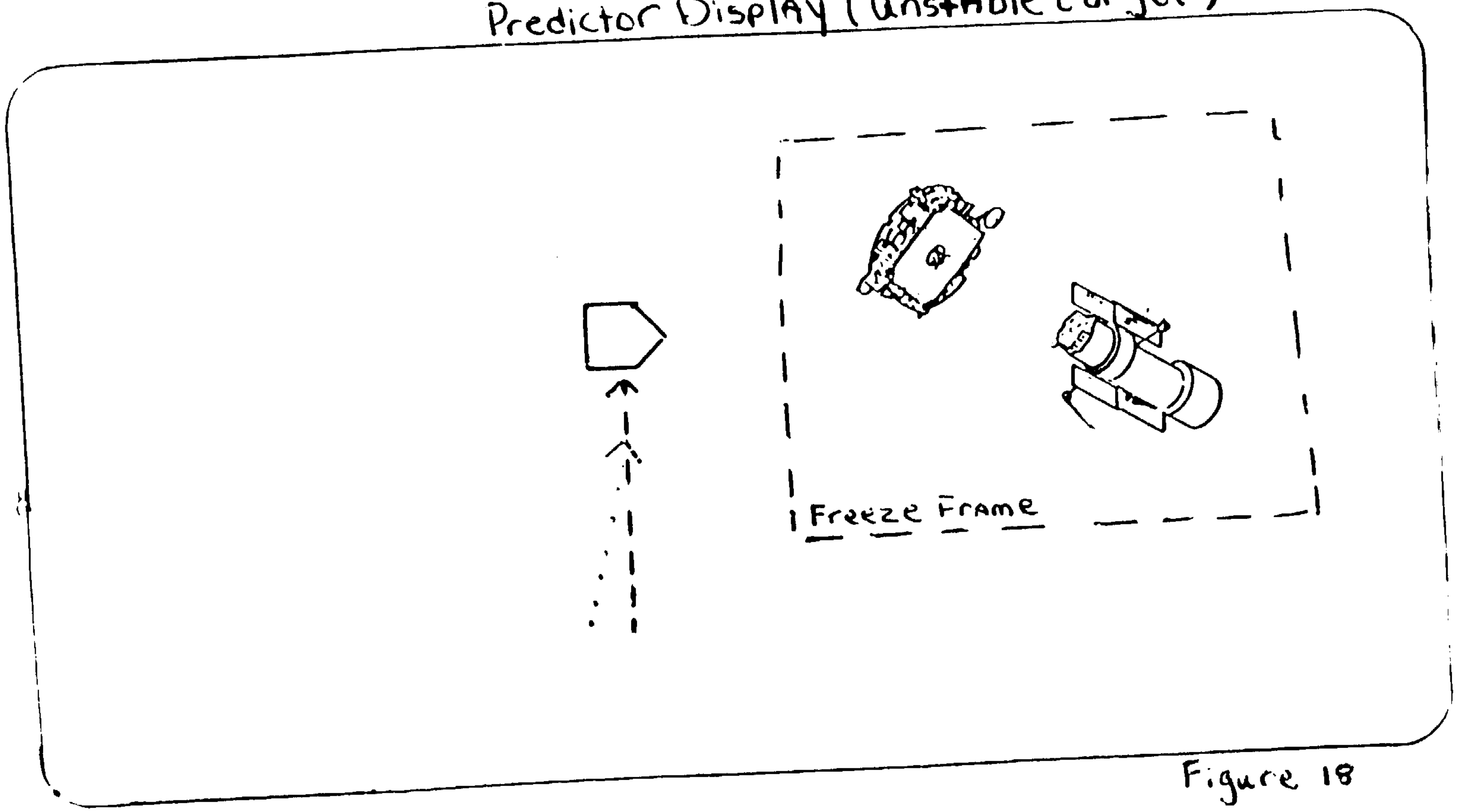

Figure 18

consideration be given to the concept of prediction in the design of the OMV system. The transmission time delay that will be characteristic of such a complex remote system could be compensated for by a predictor display as well as relieving the operator of complex algorithm computations. Wulfeck (1973) stated that the efficacy of a predictor display depends upon prediction span, repetition rate, operator response model, and display format. It is beyond the scope of this paper to determine specifications for these factors. Only by simulation will the most effective predictor display for the OMV system be determined.

In a complex operational environment such as the OMV poses, factors can work together to cause performance degradation. High workload and time delays can be seen as the two most potentially threatening causes of performance deterioration in the OMV.

Because time delay is inherent in any man-machine system, especially when dealing with the vast distances particular to the remotely operated OMV system, compensation becomes a priority issue. Because of problems posed by the new and unique OMV system, it is practically impossible to generalize compensation techniques found in the previously discussed research to the OMV. However, findings on the concepts can be applied toward simulation and research unique to the OMV. Findings in the area of prediction have been particularly promising in other types of aircraft. Simulations can help to find the effects of time delay that will pertain to a nominal OMV mission. Once the effects are determined, simulation can again determine the parameters that should be used in the implementing of the most effective predictor display.

In other areas of human performance issues, as with predictor displays, design parameters specific to the OMV itself must be determined. Once determined, the proper means of combating the detrimental effects of high workload and time delay can be implemented.

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PRELIMINARY PARTIAL TASK ANALYSIS

The following preliminary partial task analysis was undertaken in order to more clearly outline the procedural requirements of the OMV pilot during a typical OMV mission. This analysis also identifies possible manipulative problems and/or human errors that could potentially occur.

Each step of the docking and proximity operations is divided into task behaviors and task components.

The task behavior division deals with the actual instruments and controls. The task components portion deals with the perceptual processes and physical actions that are required of the OMV pilot.

It should be noted that even if the errors that are pointed out are not highly probable, these are the errors that are most likely. Any likelihood of error should be paid attention and given consideration in the design process.

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
1000 to 200 FEET				
1. Select Fuel Type	FUEL switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,HYD part of switch lights up	
2. Set Sense Mode	SENSE +X switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,Switch lights up	
3. Enable Attitude Control	ATT CNTL switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,ENABLE part of switch lights up	
4. Enable Hand Controllers	HND CNTL switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,ENABLE part of switch lights up	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR SHORT TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT OR RIGHT HAND TA
1000 to 200 FEET						
1.	VIS-Scan side instrument panel, Locate FUEL switch, HYD part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position,	Determining which type of fuel is needed	Must use gross motor and fine motor movements simultaneously	Accidental activation of REF or THR ISO switches	LEFT
2.	VIS-Scan side instrument panel, Locate +X SENSE switch, Switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that +X sense should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of -Y or -Z switch	LEFT
3.	VIS-Scan side instrument panel, Locate ATT CNTL switch, ENABLE part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that attitude control requires activation	Must use gross motor and fine motor movements simultaneously	Accidental activation of HND CNTL switch	LEFT
4.	VIS-Scan side instrument panel, Locate HND CNTL switch, ENABLE part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that hand controllers require activation	Must use gross motor and fine motor movements simultaneously	Accidental activation of ATT CNTL switch	LEFT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
5. Select PTZ Camera	CAMERAS SELECT switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,PTZ1 part of switch lights up	
6. Turn PTZ Camera On	PTZ 1 switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,Lights flash for three seconds then stay on	
7. Select Docking Camera	CAMERAS Select switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,DK1 part of switch lights up	
8. Turn Docking Camera On	DK1 switch	Depress switch	IC-Procedure checklist CC-Switch detent, CLick,Lights flash for three seconds then stay on	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR SHORT TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT or RIGHT HAND TASK
5.	VIS-Scan side instrument panel,Locate SELECT switch, PTZ1 part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that PTZ1 should be selected	Must use gross motor and fine motor movements simultaneously	Accidental activation of select switch for docking camera	Left
6.	VIS-Scan side instrument panel,Locate PTZ1 switch, ON part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that PTZ1 camera should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of PTZ2 or DK1 switch	Left
7.	VIS-Scan side instrument panel,Locate SELECT switch, DK1 part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that DK1 should be selected	Must use gross motor and fine motor movements simultaneously	Accidental activation of select switch for PTZ camera	Left
8.	VIS-Scan side instrument panel,Locate DK1 switch, ON part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that DK1 camera should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of DK2 or PTZ1 switch	Left

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
9. Set Upper Monitor To Display PTZ Data	UPPER MONITOR switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,PTZCAM part of switch lights up,PTZ data appears on upper monitor	Docking camera data may also be displayed on upper monitor
10. Set Lower Monitor To Display PTZ data	LOWER MONITOR switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,PTZCAM part of switch lights up,PTZ data appears on lower monitor	Docking camera data may also be displayed on lower monitor
11. Select Radar A	RADAR SELECT switch	Depress switch	IC-Procedure checklist CC-Switch detent, Click,A part of switch lights up	
12. Turn Radar On	RADAR A ON/OFF switch	Depress switch	IC-A portion of RADAR SELECT switch lights up CC-Switch detent, Click,ON part of switch lights up	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT o RIGHT HAND TA
9.	VIS-Scan side instrument panel,Locate UPPER MONITOR switch,PTZCAM part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that PTZ data should be on upper monitor	Must use gross motor and fine motor movements simultaneously	Accidental activation of DCKCAM part of switch or LOWER MONITOR switch	Left
10.	VIS-Scan side instrument panel,Locate LOWER MONITOR switch,PTZCAM part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position,	Determining that PTZ data should be on lower monitor	Must use gross motor and fine motor movements simultaneously	Accidental activation of DCKCAM part of switch	Lef
11.	VIS-Scan side instrument panel, Locate RADAR SELECT switch,A part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that radar A should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of of B part of switch	LEFT
12.	VIS-Scan side instrument panel, Locate RADAR A ON/OFF switch,ON part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that radar A should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of RADAR B	LEFT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
13. Set Translational Thruster To Continuous Acceleration Mode	TRANSLATION ACCEL button	Depress TRANSLATION ACCEL button	IC- CC-Switch detent, Switch lights up	Axes may be set individually
14. Set Rotational Thruster To Long Pulse Mode	ROTATION LONG button	Depress ROTATION LONG button	IC- CC-Switch detent, Switch lights up	Attitudes may be set individually
15. Select Attitude Reference Frame	REF switch	Depress switch	IC- CC-Switch detent, Click,Lights flash for three seconds then stay on	Inertial Attitude Reference Frame ma be chosen
16. Turn Overlays On	OVERLAY ON /OFF switch	Depress switch	IC- CC-Switch detent, Click,ON part of switch lights up	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT or RIGHT HAND TASK
13.	VIS-Scan center control panel, Locate TRANSLATION ACCEL button, Pushbutton lights up TAC-Switch detent AUD-Click	LT-Switch position, Function of TRANSLATION ACCEL pushbutton	Determining that TRANSLATION ACCEL pushbutton should be activated		(1)Adjusting all axes when only one or two axes adjustment is required (2)Adjusting each axis individually when ACCEL is all that is neccessary	LEFT/ RIGHT
14.	VIS-Scan center control panel, Locate ROTATION LONG pushbutton, Pushbutton lights up TAC-Switch detent AUD-Click	LT-Switch position, Function of ROTATION LONG pushbutton	Determining that ROTATION LONG pushbutton should be activated		(1)Adjusting all attitudes when only one or two attitudes adjustment is required (2)Adjusting each attitude individually when LONG is all that is needed	LEFT/ RIGHT
15.	VIS-Scan side instrument panel, Locate REF LVLH switch, Lights flash for three seconds in LVLH part of switch then stay on TAC-Switch detent AUD-Click	LT-Switch position, Function of REF switch	Determining that REF LVLH should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of INERT part of switch	LEFT
16.	VIS-Scan side instrument panel, Locate OVERLAY ON/OFF, ON part of switch lights up TAC-Switch detent AUD-Click	LT-Switch position	Determining that overlays should be activated	Must use gross motor and fine motor movements simultaneously	Accidental activation of OVERLAY NEAR/ FAR switch	LEFT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
17. Select Farfield Overlay	OVERLAY NEAR/FAR switch	Depress switch	IC- OVERLAY ON switch lights up CC-Switch detent, Click, FAR part of switch lights up, Farfield icon appears on lower monitor	
18. Align Attitude With Local Vertical Reference Frame	ROTATIONAL HAND CONTROLLER (RHC)	(1) Move forward and backward for pitch rotation and/or (2) Twist side to side for yaw rotation and/or (3) Tilt side to side for roll rotation	IC- CC-ADI is nulled	Task may require one or two of the three activiti to complete
19. Activate Attitude Hold	First button on pilot's left on RHC	Depress Attitude hold switch	IC-ADI is nulled CC-ATTITUDE R HOLD, P HOLD and Y HOLD buttons light up, ADI rate indicators return to zero	Task may also b performed with ATTITUDE R HOLD P HOLD and Y HO buttons
20. Place OMV on Target V-Bar	Translational Hand Controller (LHC)	(1) Move left or right to adjust Y axis and/or (2) Move up or down to adjust Z axis	IC- CC-Target aligned in center of farfield icon	Task may requir one or two of t three activiti to complete, Task may be performed as needed

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT or RIGHT HAND TASK
17.	VIS-Scan side instrument panel, Locate OVERLAY NEAR/FAR switch, FAR part of switch lights up, Farfield overlay appears on lower monitor TAC-Switch detent AUD-Click	LT-Switch position	Determining that FAR should be depressed	Must use gross motor and fine motor movements simultaneously	Accidental activation of NEAR part of switch	LEFT
18.	VIS-Scan lower monitor and ADI TAC-Displacement AUD-Beep	LT-Right hand controller is rotational	Determining which attitude maneuvers are needed to complete task		Failure to recognize accidental activation due to lack of feedback for input	RIGHT
19.	VIS-Scan lower monitor and ADI, Scan center instrument panel, ATTITUDE R HOLD, P HOLD and Y HOLD pushbuttons light up TAC-Button detent	LT-Button position	Determining that OMV is aligned with local vertical reference frame		Accidental activation of wrong switch on RHC, Activation using three switches when only one can be used	RIGHT
20.	VIS-Scan lower monitor TAC-Displacement AUD-Beep	LT-Left hand controller is translational hand controller	Determining which maneuvers are necessary to place OMV on target V-Bar		Failure to recognize accidental activation due to lack of feedback for input	LEFT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
21. Adjust Closing Velocity	LHC	Push in or pull out LHC	IC- CC-Range rate data indicates reaching prescribed distance	Task may b[e] performed [a] needed
22. Set Translational Thruster Control To Long Pulse Mode	TRANSLATION LONG button	Depress TRANSLATION LONG button	IC- CC-Switch detent, Switch lights up	Axes may be individual[l]
23. Adjust Lateral Position	LHC	(1)Move LHC left or right to adjust Y axis and/or (2)Move LHC up or down to adjust Z axis	IC- CC-Target centered in farfield icon	Task may requir[e] one of the two activities to complete, Task may be performed as need[ed]
<u>200 TO 100 FEET</u>				
24. Set Lower Monitor To Display Docking Camera Data	LOWER MONITOR switch	Depress switch	IC- CC-Switch detent, Click,DCKCAM part of switch lights up, Docking camera data appears on lower monitor	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT c RIGHT HAND TA
21.	VIS-Scan lower monitor TAC-Displacement AUD-Beep	LT-Left hand controller is translational hand controller	Determining acceptable closing rate		Failure to recognize accidental activation due to lack of feedback for input	LEFT
22.	VIS-Scan center control panel, Locate TRANSLATION LONG pushbutton Pushbutton lights up TAC-Switch detent AUD-Click	LT-Switch position, Function of TRANSLATION LONG pushbutton	Determining which translational acceleration mode should be activated		(1) Adjusting all axes when only one or two axes adjustment is required (2) Adjusting each axis individually when LONG is all that is necessary	LEFT RIGH
23.	VIS-Scan lower monitor TAC-Displacement AUD-Beep	LT-Left hand controller is translational hand controller	Determining which maneuvers are necessary to adjust lateral position		Failure to recognize accidental activation due to lack of feedback for input	LEFT
200 to 100 FEET						
24.	VIS-Scan side instrument panel, Locate LOWER MONITOR switch, DCKCAM part of switch lights up, Docking camera data appears on lower monitor TAC-Switch detent AUD-Click	LT-Switch position, Preferred task sequence	Determining when docking camera data is needed	Must use gross motor and fine motor movements simultaneously	Accidental activation of UPPER MONITOR switch	LEF

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
25. Focus PTZ Camera	FOCUS PTZ switch	Depress IN or OUT repeatedly until camera is focused	IC- CC-Focused picture	Task may be performed at any time but most like at this time
26. Focus Docking Camera	FOCUS DCK switch	Depress IN or OUT repeatedly until camera is focused	IC-Focused upper monitor CC-Focused picture	Task may be performed at any time but most like at this time
27. Perform Attitude Maneuvers To Maintain Docking Camera On The Target	RHC	(1)Move RHC forward and backward for pitch rotation and/or (2)Twist RHC side to side for yaw rotation and/or (3)Tilt RHC side to side for roll rotation	IC- CC-ADI is nulled	Task may require one or two of the three activities to complete
28. Adjust Closing Velocity	LHC	Pull LHC out or push LHC in	IC- CC-Range rate data indicates reaching prescribed distance	Task may be performed as needed

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
29. Adjust Lateral Position	LHC	(1)Move LHC left or right to adjust Y axis and/or (2)Move LHC up or down to adjust Z axis	IC- CC-Target aligned in farfield icon	Task may be performed as needed
30. Focus Docking Camera	FOCUS DCK switch	Depress IN or OUT repeatedly until picture is focused	IC- CC-Focused picture	Task may be performed at any time but most likely at this time
<u>100 to 50 FEET</u>				
31. Switch To Cold Gas Thruster RCS	FUEL switch	Depress switch	IC- CC-Switch detent, Click,Lights flash for three second in GN2 part of switch then stay on	
32. Tilt PTZ Camera Down	TILT switch	Depress DOWN part of switch	IC- CC-PTZ camera moved down	Task may performed needed

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. ASK or TEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT or RIGHT HAND TASK
9.	VIS-Scan lower monitor TAC-Displacement AUD-Beep	LT-Left hand controller is translational hand controller	Determining which maneuvers are necessary		Failure to recognize accidental activation due to lack of feedback for input	LEFT
0.	VIS-Scan side instrument panel Locate FOCUS DCK switch, Scan lower onitor, Focused picture TAC-Depression	LT-Switch position ST-Location of docking camera data on lower monitor	Determining acceptable display clarity	Must release LHC	Accidental activation of FOCUS PTZ switch	LEFT
1.	VIS-Scan side instrument panel, Locate FUEL switch, Lights flash for three seconds then stay on in GN2 part of switch TAC-Switch detent AUD-Click	LT-Switch position Preferred task sequence	Determining if cold gas is needed	Must use gross motor and fine motor movements simultaneously	Forgetting preferred task sequence, Accidental activation of REF or THR ISO switch	LEFT
2.	VIS-Scan side instrument panel, Locate TILT switch, Scan upper monitor TAC-Depression	LT-Switch position, Preferred task sequence ST-Location of PTZ data on upper monitor		Must release LHC, Must use gross motor and fine motor movements simultaneously	Forgetting preferred task sequence	LEFT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
33. Pan PTZ Camera	PAN switch	Depress LEFT part of switch	IC-PTZ camera down CC PTZ camera moved to the left	Task may be performed a needed
34. Adjust Closing Velocity	LHC	Pull LHC out or push LHC in	IC- CC-Range rate data indicates reaching prescribed distance	
<u>50 FEET to DOCK</u>				
35. Extend RMS Docking Mechanism	FIXTURE switch	Depress switch	IC- CC-Switch detent, Click,Lights in XTEND part of switch flash for three seconds then stay on	
36. Switch To Nearfield Overlay	OVERLAY NEAR/FAR switch	Depress switch	IC- CC-Switch detent, Click,NEAR part of switch lights up, Nearfield overlay appears on lower monitor	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT or RIGHT HAND TAS
33.	VIS-Scan side instrument panel,Locate PAN switch, Scan upper monitor TAC-Depression	LT-Switch position, Preferred task sequence ST-Location of PTZ data on upper monitor		Must release LHC, Must use gross motor and fine motor movements simultaneously	Forgetting preferred task sequence	LEFT
34.	VIS-Scan lower monitor TAC-Displacement AUD-Beep	LT-Left hand controller is translational hand controller	Determining which maneuvers are necessary		Failure to recognize accidental activation due to lack of feedback for input	LEFT
50 FEET to DOCK						
35.	VIS-Scan side instrument panel,Locate FIXTURE switch, Lights flash for three seconds then stay on in XTEND part of switch TAC-Switch detent AUD-Click	LT-Switch position	Determining that docking mechanism should be extended		Accidental activation of FIXTURE OPEN/ CLOSE switch	LEFT
36.	VIS-Scan side instrument panel,Locate OVERLAY NEAR FAR switch,NEAR part of switch lights up,Nearfield overlay appears on lower monitor TAC-Switch detent AUD-CLick	LT-Switch position, Preferred task sequence	Determining that NEAR part of switch should be depressed		Accidental activation of OVERLAY ON/OFF switch	LEFT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
37. Switch Translational Thruster to Short Pulse Mode	TRANSLATION SHORT button	Depress TRANSLATION SHORT button	IC-Flashing of lights in OVERLAY NEAR/FAR switch CC-Switch detent, Switch lights up	Axes may be se individually
38. Switch Rotational Thruster to Short Pulse Mode	ROTATION SHORT button	Depress ROTATION SHORT button	IC- CC-Switch detent Switch lights up	Attitudes may b set individuall
39. Focus Docking Camera	FOCUS DCK switch	Depress IN or OUT repeatedly until picture is focused	IC- CC-Focused picture	Task may be performed at any time but most like at this time
40. Perform Rotational Attitude Maneuvers	RHC	(1)Move RHC forward and backward for pitch rotation and/or (2)Twist RHC side to side for yaw rotation and/or (3)Tilt RHC side to side for roll rotation	IC- CC-White dot of docking aid pole is in the proper location on the docking target	Task may requi one or two of th three activitie to complete

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT or RIGHT HAND TASK
37.	VIS-Scan center instrument panel, Locate TRANSLATION SHORT pushbutton, Pushbutton lights up TAC-Switch detent	LT-Switch position, Function of TRANSLATION SHORT pushbutton	Determining that TRANSLATION SHORT pushbutton should be activated		(1)Adjusting all axes when only one or two axes adjustment is required (2)Adjusting each axis individually when SHORT is all that is necessary	LEFT/ RIGHT
38.	VIS-Scan center instrument panel, Locate ROTATION SHORT pushbutton, Pushbutton lights up TAC-Switch detent	LT-Switch position, Function of ROTATION SHORT pushbutton	Determining that ROTATION SHORT pushbutton should be activated		(1)Adjusting all attitudes when only one or two attitudes adjustment is required (2)Adjusting each attitude individually when SHORT is all that is necessary	LEFT/ RIGHT
39.	VIS-Scan side instrument panel,Locate FOCUS DCK switch,Scan lower monitor, Focused picture TAC-Depression	LT-Switch position ST-Location of docking camera data on lower monitor	Determining acceptable display clarity	Must release LHC	Accidental activation of FOCUS PTZ switch	LEF
40.	VIS-Scan lower monitor TAC-Displacement AUD-Beep	LT-Right hand controller is rotational hand controller	Determining which attitude maneuvers are necessary		Failure to recognize accidental activation due to lack of feedback for input	RIGHT

DOCKING AND PROXIMITY OPERATIONS

TASK BEHAVIORS

a. TASK or STEP	b. INSTRUMENT or CONTROL	c. ACTIVITY	d. INITIATION and COMPLETION CUES	e. REMARKS
41. Turn Attitude Hold On	First button on pilot's left on RHC	Depress attitude hold button	IC- CC-ATTITUDE R HOLD, P HOLD and Y HOLD buttons light up, ADI rate indicators return to zero	Task may also be performed with ATTITUDE R HOLD, P HOLD and Y HOL buttons
42. Adjust Closing Velocity	LHC	Pull back on LHC	IC- CC-Target image in lower monitor	Task may be performed as needed
43. Close The Grapple	Trigger switch on RHC	Pull trigger switch on RHC	IC-Docking aid in docking reticule CC-	

DOCKING AND PROXIMITY OPERATIONS

TASK COMPONENTS

f. TASK or STEP	g. SCANNING, PERCEPTUAL OR ANTICIPATORY, REQUIREMENTS	h. RECALL REQ'S, LONG AND/OR TERM	i. INTERPRETING REQ'S	j. MANIPULATIVE PROBLEMS	k. LIKELY HUMAN ERRORS	l. LEFT OR RIGHT HAND TAS
41.	VIS-Scan lower monitor and ADI, Scan center instrument panel, ATTITUDE R HOLD, P HOLD and Y HOLD pushbuttons light up TAC-Button detent	LT-Button position	Determining that Attitude hold should be activated		Accidental activation of wrong button on RHC, Activation using three switches when only one can be used	RIGH
42.	VIS-Scan lower monitor and docking aid TAC-Displacement AUD-Beep	LT-Left hand controller is translational hand controller	Determining which maneuvers are necessary	Range rate data no longer available	Failure to recognize accidental activation due to lack of feedback for input	LEFT
43.	VIS-Scan lower monitor and docking reticule, Scan side instrument panel, CLOSE part of FIXTURE OPEN/CLOSE switch lights up TAC-Switch detent	LT-Switch position	Determining that target is in docking envelope		Accidental activation of FIXTURE XTEND/ RTRAC switch, Missing the target	RIGH

APPENDIX

APPENDIX

Layout of the console, characteristics of the controls and displays located on the console, and control functions will be covered in this appendix.

LAYOUT OF THE CONTROLS

Video Monitors - Currently, the GCC includes two video monitors in a one above the other, or stacked arrangement. These monitors will be positioned directly in front of the pilot, 22 inches from the resting eye position, and with the screen surface perpendicular to the eyes. The lower monitor will be 30 degrees below the resting eye position and the upper monitor will be a maximum of 15 degrees above the resting eye position. Each will have a vertical tilt of +/- 5 degrees minimum (see Figure 1) (GCC MMI Requirements Document, 1988).

Side Instrument Panels - The side instrument panels will be a maximum of 28 inches from and perpendicular to the shoulder points.

Hand Controllers - The hand controllers will be centered in front of the pilot. They will be 14 inches forward of the spinal plane and 22 inches apart. The rotational hand controller will be mounted on the right and the translational hand controller on the left.

OMV Orbital Maneuvering Vehicle

OVERLAY A

TRW Space & Technology Group

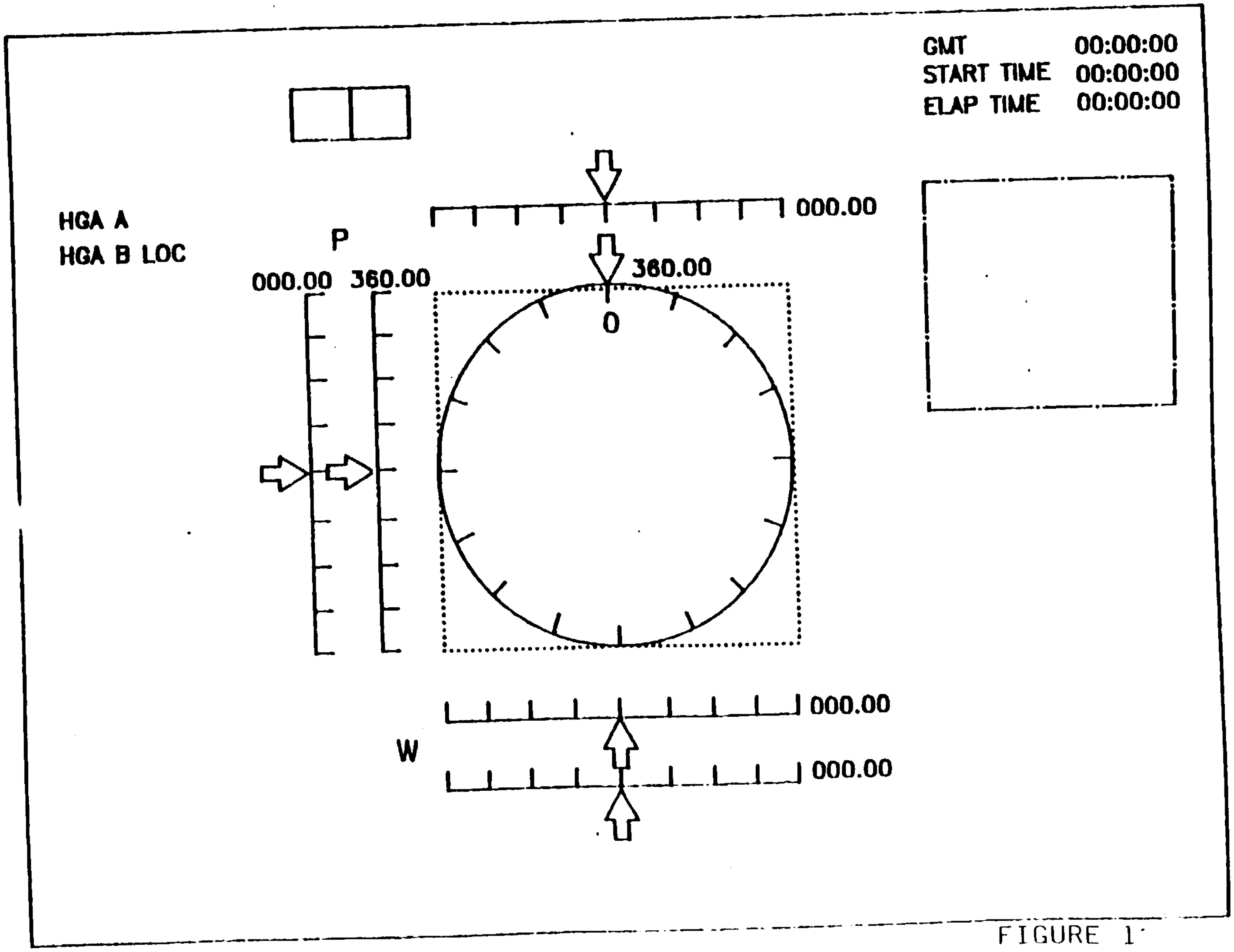

FIGURE 1

<u>Switches</u> - The switches will be placed at a maximum of 28 inches from the shoulder points. It is specified that placement of the switches will be such that reach interference with hand controls is minimized.

<u>Grouping of Switches</u> - Switches will be grouped according to function. Different groups and subgroups will be separated by color, shape, and spacing. There are three switch function groups: 1) <u>Attitude control functions</u>- these are used for controlling thruster modes and commanding attitude and rate hod. Attitude control functions are most frequently used. 2) <u>General purpose docking functions</u> - these switches will be used for grapple commands, reference frame, fuel selection, camera commands, lights and radar. General purpose docking switches are moderately used. 3). <u>Emergency functions</u> - these are the switches included in the Collision Avoidance Maneuver and are rarely used.

Switches will be placed according to frequency of use. Thus, attitude control functions will be placed in a switch area closest to the pilot. General purpose docking functions will be placed in the next possible switch area. Emergency function switches will be isolated from other switches so that deliberate action will be required for activation. Also, hinged protective covers will be used to prevent accidental activation.

CHARACTERISTICS OF TRW OMV CONTROLS AND DISPLAYS

Rotational Hand Controller - The rotational hand controller (RHC) will be of the control grip type. It will provide three axes of control. Each of the three axes of the RHC will have dual mechanical switch contacts. The time skew between closing of the contacts will be less than 5 milliseconds. The RHC will include four mechanical switches located on the top of the device. Each of these four switches will have redundant, mechanically independent contacts. The time skew between closing of the contacts will be less that 5 milliseconds.

Translational Hand Controller - The translational hand controller (THC) will be of the T-type. It will provide three axes of control. Each of the three axes will have dual mechanical switch contacts. The time skew between closing of the contacts will be less than 5 milliseconds.

Switches - Ninety-six switches will be included in the pilot station. Each switch will have dual, mechanically independent contacts. The time skew between closing of the contacts will be less than 5 milliseconds.

Status Displays - Each hand controller will have a dedicated audible annunciator. A separate single switch will be provided to disable each audible annunciator. Each of the four switches in the RHC will have four independently lightable status indicators. It will be possible to independently label each indicator with a light character mnemonic. Switch status indicators will include four independently lightable status indicators for each switch. The four indicators will be integral with the switch pushbutton. It will be possible to independently label each switch with two light character mnemonics (OMV Equipment Specifications, August 1988).

Displays - The GCC will provide the pilot with two video monitors. Pilot displays that are required are two overlays, a docking reticule, and a far field display. Data representation can vary from textual to graphic.

A minimum of two fixed overlays will be provided. Either overlay will be capable of being displayed on either video monitor.

Overlay A will contain:

GMT

Start Time

Elapsed Time

Hand Controller Input Indicators

ADI

PTZ Camera Video

HGA Data (see Figure 2)

Overlay B will contain:

Rate vs. Range

Delta vs. Data

PTZ AZ/EL

Radar AZ/EL

Communication events (see Figure 3)

The Docking Reticule will contain:

Docking Target Envelope

Rate Data

Attitude Hold Data

Rate Hold Data

Latch Sensor Data (see Figure 4)

The Far Field ICON - will contain a set of concentric circles of predefined radii to aid in target range determination. (see Figure 5)

The Attitude Determination Indicator (ADI) - will represent attitude and rate information graphically and numerically. (see Figure 6)

Required operations terminal displays include; 1) telemetry pages, 2) logs (event, error, alarms, commands),

OVERLAY B

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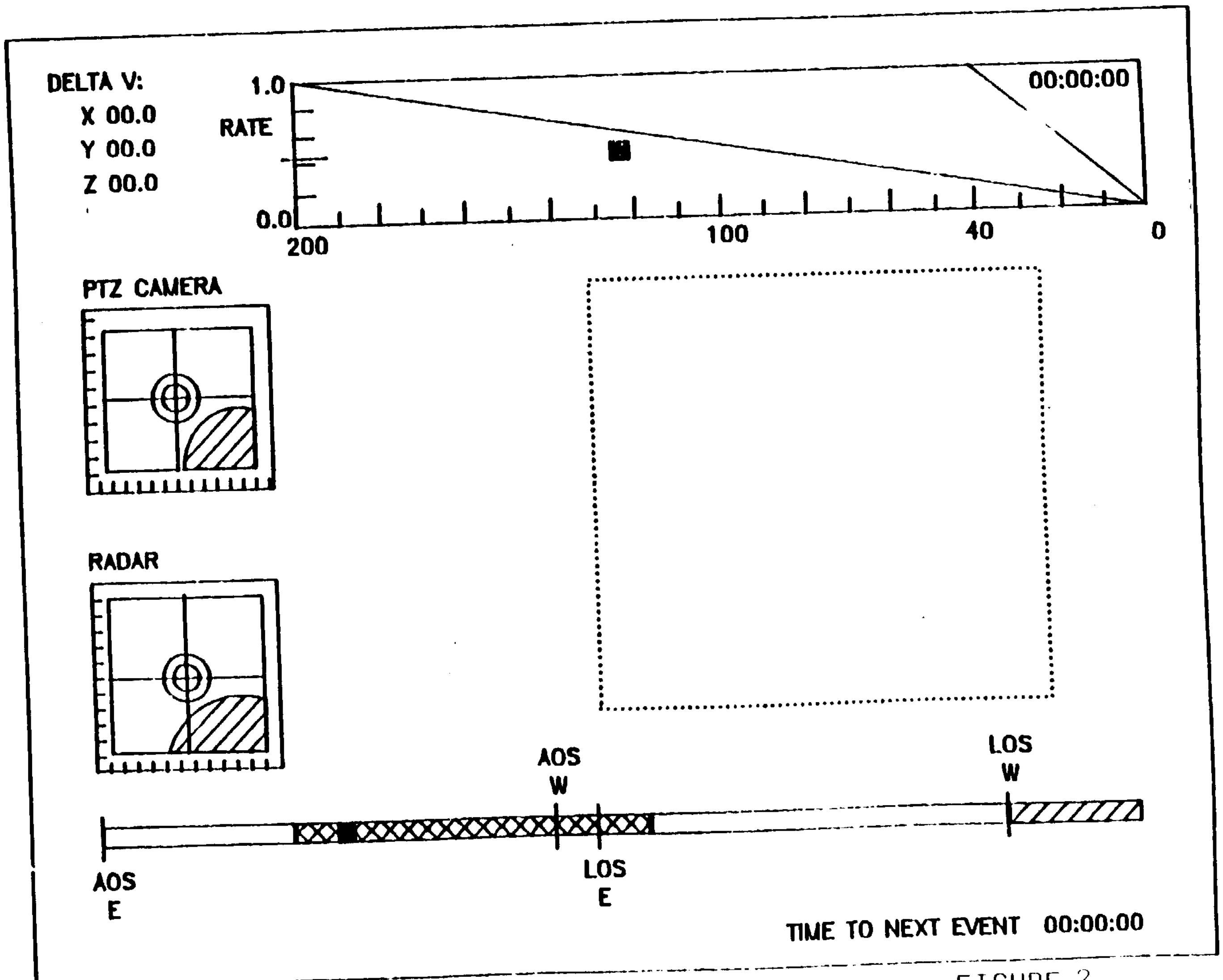

FIGURE 2

OMV Orbital Maneuvering Vehicle

DOCKING RETICULE

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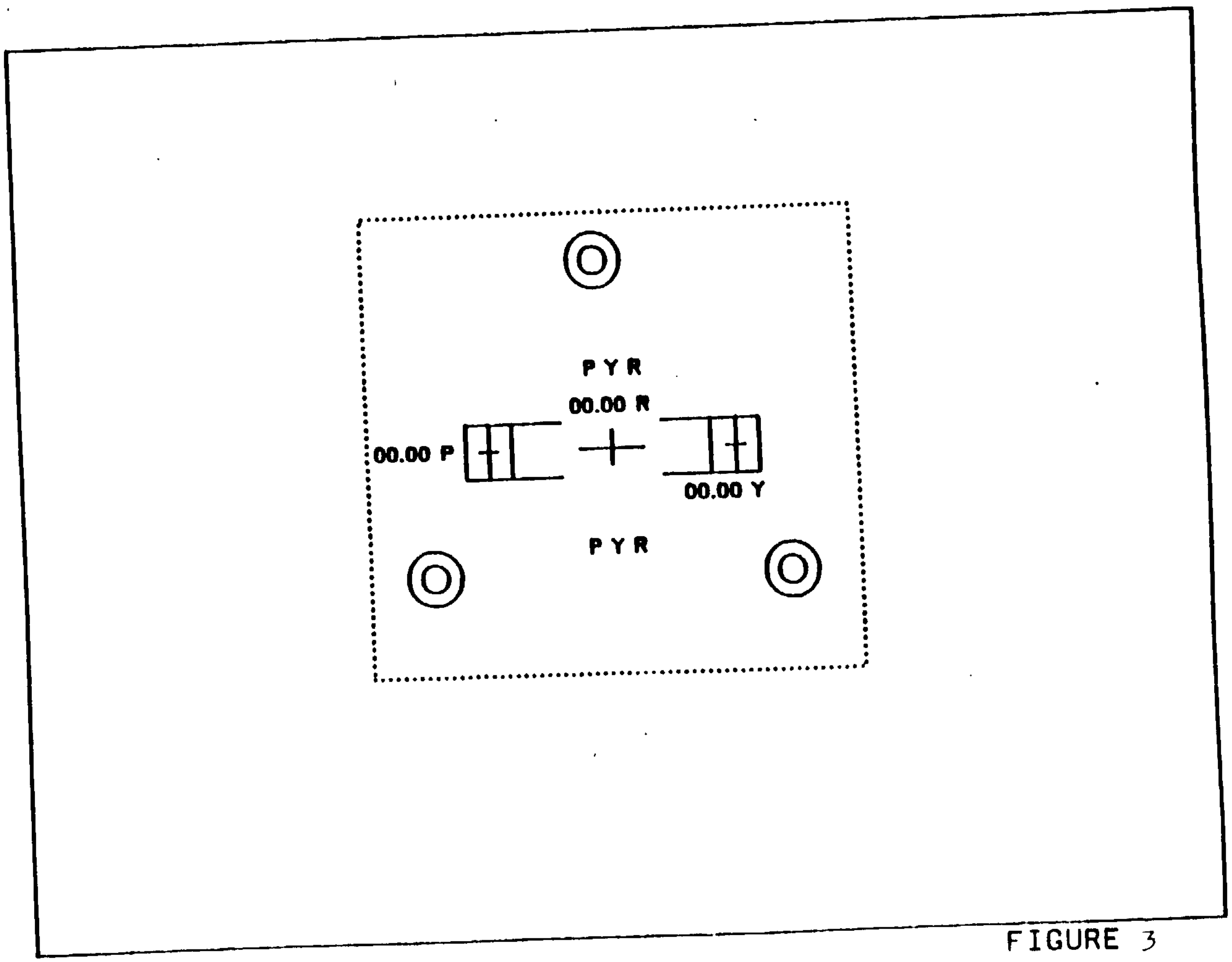

FIGURE 3

FAR FIELD ICON

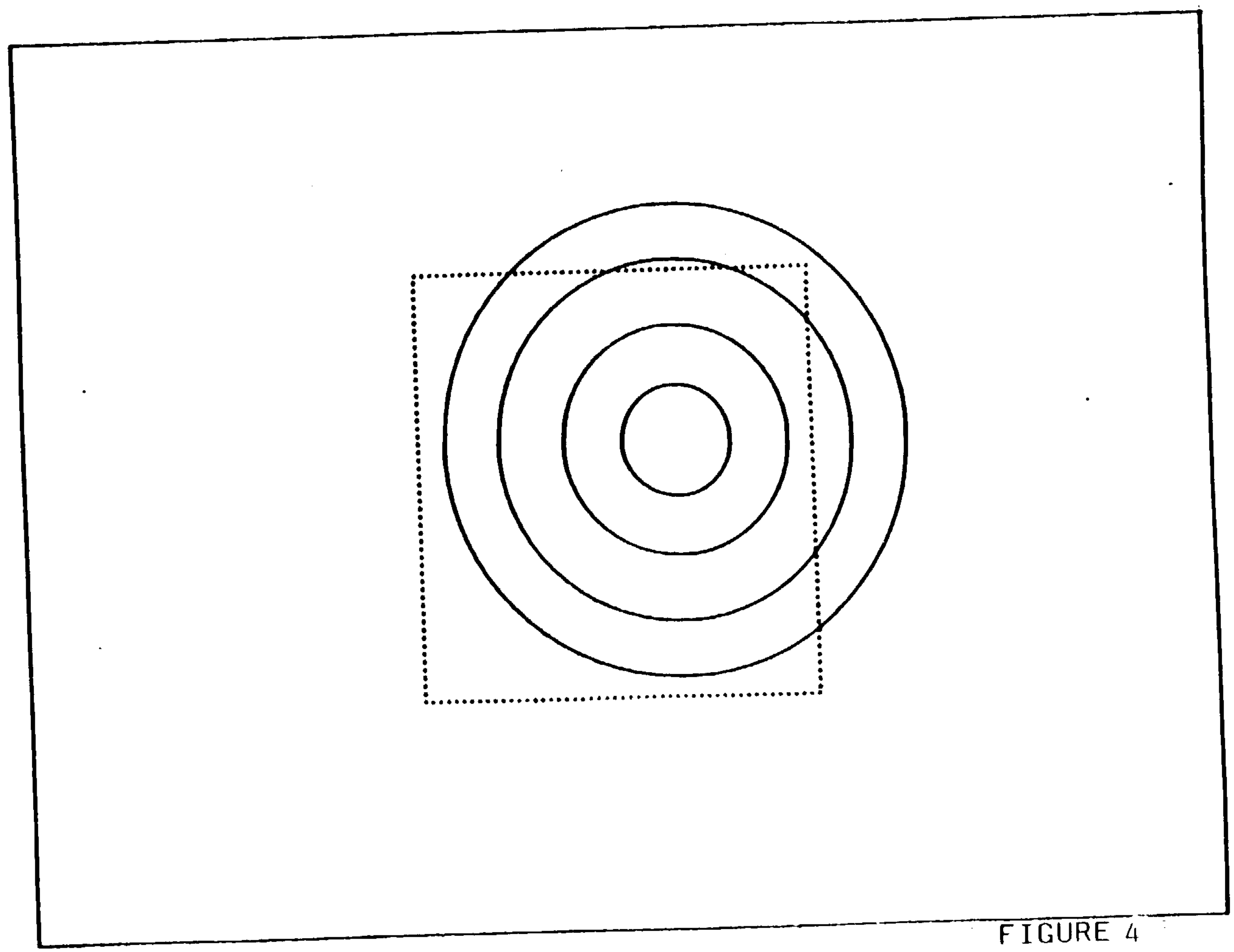

FIGURE 4

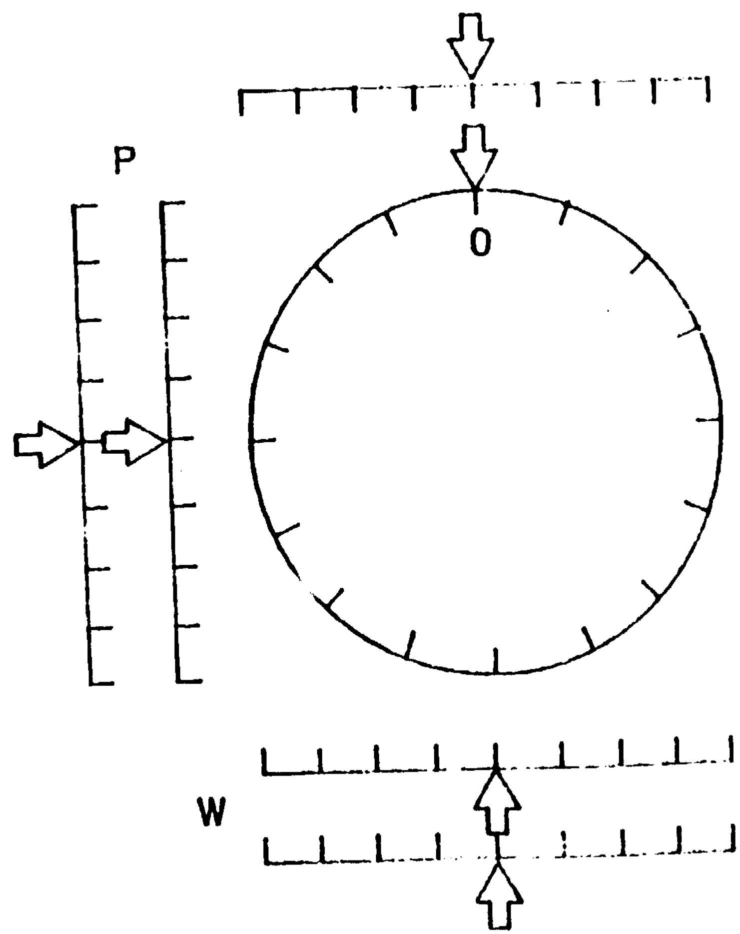

FIGURE 5

ATTITUDE DETERMINATION INDICATOR

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Orbital Maneuvering Vehicle

PAGE #
NOSYNC

TITLE

GMT DAY/00:00:00
MET DAY/00:00:00

SUBTITLE
DATAXXXX ------- UNIT
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DATAXXXX ------- UNIT

TITLE LOG

DAY/00:00:00 LOG INFORMATION LINE
DAY/00:00:00 LOG INFORMATION LINE
DAY/00:00:00 LOG INFORMATION LINE
DAY/00:00:00 LOG INFORMATION LINE

FIGURE 6

3) data plots and 4) status reports (equipment, mission).

Telemetry Pages - The telemetry pages, shown in Figure 7 will be a maximum of 24 lines by 80 columns. The top two lines will contain time, title, page number, and sync data. Lines four through 18 will be separated into three equal columns for display of telemetry data with subtitles; Positioning and grouping of telemetry and subtitles will be flexible; any line within this region will accept telemetry, subtitle, or blank. Lines 20 through 24 will display a scrolling log; the type of log and subgroup selection of data from the log will be flexible.

Alarms - Alarms will be presented visually and audibly. Color, graphics, text, flashing and reverse video will be used to present alarms on displays. Uniquely identifiable sounds will constitute the audible alarm capability (OMV PDR, August, 1988).

CONTROL FUNCTIONS

Left-Hand Switch Panel

1. Thruster system select switch - used to choose between the hydrazine RCS with 15 pound thrusters (nominal), or the GN2 RCS with 5 pound thrusters.
2. Thruster table select switch - allow access to different sets of thrusters to perform standard

translation and rotation maneuvers. Four different thruster tables are available to the pilot. Each table is to be set prior to mission, and any of the four tables can be chosen at any time during the mission.

3. Sense switch - is used to change the body pointing vector reference on the OMV. Attitude displays and the hand controllers are keyed to this switch to allow the pilot to fly the OMV in a different sense and not change pilot techniques.
4. Grapple extend switch - allows the pilot to extend the RGDM out of the OMV prior to docking.
5. Grapple engage - has two locations. It is located on the rightmost switch on the left-hand panel and is the rightmost switch on the RHC. The grapple engage switch sends the command to close the snares on the RGDM or the latches on the TPDM for a complete dock.
6. Hand controls - allows the pilot to isolate the hand controllers and prevent inadvertent commands from being issued during non-piloting periods of operation.
7. Translation X, Y, and Z modes - used to select the acceleration mode for each of the three translation axes. Each axis can be commanded into continuous or

pulse acceleration mode.

8. Translation pulse size - allows the pilot to choose between two pulse acceleration sizes. They are marked as short pulse and long pulse, and can be set to any value prior to the start of the mission. This switch affects all translation axes that are set on pulse acceleration mode.

9. Rotation, pitch, yaw, and roll modes - are three switches that select the acceleration mode for each of the three rotational axes. Each axis can be commanded into continuous or pulse acceleration mode.

10. Rotation pulse size - allows the pilot to choose between two pulse acceleration sizes. This switch's two choices are marked as long pulse and short pulse, and can be set to any value prior to the start of the mission. This switch affects all rotational axes that are set on pulse acceleration mode.

11. Attitude hold for pitch, yaw, and roll - Three switches, one for each axis, that enable or disable the attitude hold function for each axis. Also, there is a single thumbswitch on the RHC (leftmost) that activates attitude hold in all three axes.

12. Error deadband select - Allows the pilot to choose between coarse and fine attitude hold accuracy.

13. Rate hold for pitch, yaw and roll - Three switches, one for each axis, that enables or disables the rate hold function for each axis.

14. Rate error deadband select - Allows the pilot to choose between coarse and fine attitude rate accuracy.

15. Rotation reference frame - Allows the pilot to choose either the LVLH or Inertial Reference frames to operate in.

16. Pitch, yaw and roll controls - Three switches that allow the pilot to independently enable or disable hand controller inputs in any axis.

Right-hand switch panel

1. Spot lights - controls the spotlights on the OMV that are used when the OMV is in an eclipse period.

2. Nav lights - controls the navigation lights on the OMV which are used when in proximity to the Orbiter or the Space Station.

3. Radar enable/disable - controls the radar which is used in the programmed mode to locate the target and guide the OMV to the hand-off point 1000 feet from the target. Then, the radar is used to help the

operator identify and overcome the initial position and velocity hand-off dispersion and close towards the target. The radar is used to within 35 feet and turned off.

4. Delta-V null - allows the pilot to null the accumulated delta-v display shown on one of the monitors. It aids in maneuvering heavy payloads from the hand-off point.

5. Pan/tilt/zoom camera controls - switches that control the actions of the pan/tilt/zoom camera mounted on the rim of the OMV and deployed outward on a boom.

   pan - left and right
   tilt - up and down
   zoom - magnify

6. Image select, upper and lower monitors- The upper and lower monitors each have three sets of switches that allow the pilot to select an image. Images can be from any of the cameras or from dedicated information displays.

7. Overlay select, upper and lower monitors- Each of the two monitors have two sets of switches that allow the operator to select overlays. The overlays include graphics or text images that are written on top of the images coming from the cameras. Overlays assist the

pilot in aligning the OMV with a target for a successful dock.

8. Pan/tilt/zoom camera screen overlay scale control - allows the pilot to change the scales of the pan/tilt/zoom camera angle displays between coarse and fine.
9. Radar Az/El screen overlay scale control- allows the pilot to change the scales of the radar azimuth and elevation displays between coarse and fine.
10. Radar LOS screen scale control- allows the pilot to change the scales of the radar LOS data between coarse and fine.
11. Attitude screen display scale control - allows the pilot to change the scales of the attitude display between coarse and fine.
12. Attitude rate screen display scale control- allows the pilot to change the scales of the attitude rate display between coarse and fine.

Hand Controllers

1. Translation hand controller (THC)- provides forward/ backward, upward/downward, and left/right translation control of the OMV. The THC is mounted to the left of the pilot and is to be controlled by the left hand.
2. Rotation hand controller (RHC) - provides the pilot

with +/- pitch, +/- yaw, and +/- roll attitude control of the OMV. The RHC contains four switches:

one trigger switch - not used

three thumbswitches - leftmost; activates attitude hold in all axes.

center; activates text on screen

rightmost; closes grapple.

(RGDM/TPDM Pilot Engineering Simulations, May 11, 1988)